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OPERATING PROCEDURES

DEPARTMENT OF THE NAVY
U.S. NAVAL OBSERVATORY

PRECISE TIME AND TIME INTERVAL EQUIPMENTS

NAVOBSY – TS/PTTI SOP-81

U.S. NAVAL OBSERVATORY
34th and Massachusetts Ave., NW
Washington, D.C. 20390

IN REPLY REFER TO

62
2900
Ser 141
12 Feb 1981

LETTER OF PROMULGATION

NAVOBSY TS/PTTI SOP-81, "Operating Procedures for Precise Time and Time Interval Equipments" was developed under the direction of the Superintendent, U. S. Naval Observatory, and is promulgated for use by DOD activities conducting PTTI operations. The publication is designed to provide a central source of information and instructions for operating personnel in the PTTI center of any DOD activity.

NAVOBSY TS/PTTI SOP-81 supersedes NAVOBSY TS/PTTI OIM of 1 June 1973.

NAVOBSY TS/PTTI SOP-81 is an unclassified, non-registered publication.

NAVOBSY TS/PTTI SOP-81 is effective upon receipt.

Permission is granted to copy or make extracts from this publication without the consent of the Superintendent, U. S. Naval Observatory.

Correspondence concerning this publication should be addressed to the Superintendent, U. S. Naval Observatory, Washington, D. C. 20390.

Raymond A. Vohden

Raymond A. Vohden
Captain USN
Superintendent,
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OPERATING PROCEDURES

PRECISE TIME AND TIME INTERVAL EQUIPMENTS

NAVOBSY – TS/PTTI SOP-81

12 FEBRUARY 1981

CHANGE RECORD

Change No.	Reason for Change	Entered By	Date

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CHAPTER 1
INTRODUCTION

The mission of the U.S. Naval Observatory, according to OPNAVINST 5450.90B of 16 December 1969, is to "make such observations of celestial bodies, natural and artificial, derive and publish such data as will afford to United States Naval vessels and aircraft, as well as to all availing themselves thereof, means for safe navigation, including the provision of accurate time."

The practical application of this mission, insofar as time is concerned, is for the U.S. Naval Observatory (NAVOBSY) to serve as the operational reference for the official United States time of day, as opposed to the National Bureau of Standards' (NBS) responsibility for the unit of time and frequency.

The Time Service Division of the NAVOBSY performs several functions:

a. It operates photographic zenith tubes (telescopes) to determine Universal Time (UT).

b. It operates, under agreement with the National Science Foundation (NSF), a connected radio element interferometer at the National Radio Astronomy Observatory in Green Bank, West Virginia, for the determination of UT with radio techniques.

c. It operates a large bank of atomic clocks (more than 20) as the basis of an extremely reliable and uniform atomic time scale.

d. It monitors and controls the worldwide dissemination of Department of Defense (DoD) Precise Time and Time Interval (PTTI).

e. It transports portable atomic clocks worldwide for time synchronization to assure worldwide continuity of precision.

f. It promptly publishes and distributes Time Service Announcements regarding measurments of, and information on, many electronic systems useful for time dissemination.

The NAVOBSY, along with 60 other observatories and standards laboratoriies throughout the world, contributes measurements, to the Bureau International de l'Heure (BIH) in Paris, France, which combines the results into final BIH values of UT1 (see chapter 16). The NAVOBSY is the only organization in the United States that determines UT1 operationally. It distributes BIH Circular D for the BIH in the United States.

The United States Department of Defense (DoD) provides frequency and time signals throughout the world. These include many different radio frequencies, satellite signals, and portable clocks. These can provide very high resolution time synchronization, one-tenth microsecond or better. Within the DoD, the NAVOBSY has been given management responsibilities to accomplish overall Precise Time and Time Interval (PTTI) objectives at minimum cost (DoD Directive 5160.51 of 31 August 1971).

1.1 PRECISE TIME STATIONS

The NAVOBSY accomplishes its global responsibilities with a system of cooperating Precise Time Stations (PTS) and Precise Time Reference Stations (PTRS). A PTS is a station whose time is traceable to the NAVOBSY Master Clock and falls within the definitions of precise time in OPNAVINST 5450.90B. A PTRS participates actively with the NAVOBSY in PTTI activities. A PTRS is a special class of PTS that, by agreement, maintains at least one atomic clock coordinated with the NAVOBSY Master Clock; is linked to the NAVOBSY via portable clock and at least one other high precision time transfer technique; can transfer time with a precision of 100 nanoseconds; and has less than 1 microsecond time uncertainty with respect to the NAVOBSY. The PTRS provides an independent, high quality, accessible timekeeping capability to serve as a reference point for operations in a particular area. However, any of the PTS clocks can be used to gain access to the NAVOBSY Master Clock by correcting a reading against the PTS clock with the published difference (NAVOBSY Master Clock - PTS). Table 1-1 lists Precise Time Stations and their locations.

It should be noted that many of the PTTI dissemination systems can also provide PTTI services to users who have access to their facilities. These systems include: LORAN-C, VLF, Omega, Navy Metrology Labs, PMELS, NASA sites, HF, TV, SATCOM, TRANSIT, GPS/NAVSTAR, etc.

Table 1-1 Precise Time Stations

Precise Time Station

U.S. Naval Observatory, Washington, D.C.*

U.S. Naval Observatory, Time Service Substation, Richmond, Florida*

National Bureau of Standards, Boulder, Colorado*

Hewlett Packard, Santa Clara, California*

Hewlett Packard, Geneva, Switzerland*

U.S. Navy Astronautics Group, Det. C, Wahiawa, Hawaii*

U.S. Navy Astronautics Group, Point Mugu, California

USAF PMEL, Elmendorf, Alaska*

Aerospace Guidance and Metrology Center, Newark, Ohio*

Haystack Observatory, Massachusetts

Applied Physics Laboratory, Maryland

Pacific Missile Test Center, California

USAF Vandenberg PMEL, California

Jet Propulsion Labs, California

White Sands Missile Range, New Mexico

Fairbanks AFB, Washington

Eastern Test Range, Patrick AFB, Florida

NAVSECGRP, Scotland

NAVSECGRP, Italy

NASA, Guam

NASA, Alaska

NASA, Hawaii

USCG, Japan

USCG, Canada

USCG, Faroe Islands

NBS, Hawaii

*Precise Time Reference Stations

Table 1-1 Precise Time Stations (Continued)

International Laboratories

- Paris Observatory, Paris, France
- Royal Greenwich Observatory, Greenwich, England
- National Physical Laboratory, Teddington, England
- Van Swinden Laboratory, Delft, Netherland
- Technische Universitaet Graz, Graz, Austria
- Deutsches Hydrographisches Institute, Hamburg, Germany
- Instituto Elettrotecnico Nazionale, Turin, Italy
- Physikalisch Technische Bundesanstalt, Braunschweig, Germany
- Observatoire Cantonal, Neuchatel, Switzerland
- Istituto y Observatorio de Marina, San Fernando, Spain
- Tokyo Astronomical Observatory, Tokyo, Japan
- Radio Research Laboratories, Tokyo, Japan
- Telecommunication Laboratories, Chung-Li, Taiwan
- National Research Council, Ottawa, Canada
- Division of National Mapping, Canberra, Australia

SATCOM Terminals

- Berlin, Germany
- Camp Roberts, California
- Clark AFB, Philippines
- Croughton, England
- Diego Garcia, B.I.O.T.
- Elmendorf AFB, Alaska
- Ft. Detrick, Maryland
- Finegayan, Guam
- Futenma, Okinawa
- Guantanamo Bay, Cuba
- Keflavik, Iceland
- Kwajelein, M.I.
- Lajes Field, Azores
- Landstuhl, Germany
- Naples, Italy
- Northwest, Virginia
- Shemya, Alaska
- Sunnyvale, California
- Taegu, Korea
- Wahiawa, Hawaii
- Woomera, Australia

1.2 TIME SERVICE PUBLICATIONS

In support of the control and dissemination of precise time and time interval, the NAVOBSY provides a variety of Time Service Publications that are available to subscribers. These are published in series, numbered 1 through 18, as described below and are available on request from:

Superintendent
U.S. Naval Observatory Attention: Time Service Division
34th and Massachusetts Avenue, N.W. Washington, D.C. 20390
(Telephone: 202-254-4546, AUTOVON 294-4546; TWX: 710822-1970)

Series 1 WORLDWIDE PRIMARY TIME and FREQUENCY VLF and HF TRANSMISSIONS. Includes call sign, geographic location, frequencies, radiated power, times of broadcast, etc., of radio transmissions suitable for precise time measurement. Contains sections pertaining to US. Navy time and frequency transmission, LORAN-C, Omega, National Bureau of Standards (NBS), and other time signals. (Issued as necessary)

Series 4 DAILY PHASE VALUES and TIME DIFFERENCES. Lists observed phase and/or time difference between VLF, LF, Omega, television, portable clock measurements, LORAN-C stations, and the U.S. Naval Observatory (USNO) Master Clock, UTC (USNO MC). Propagation disturbances and notices of interest for precision timekeeping are also given. (Issued weekly)

Series 5 USNO PHASE VALUES/TELETYPE MESSAGE. Lists information described in series 4 as it becomes available. TWX message for U.S. Government addresses only after submission of written justification to the Superintendent.

This information is also available via recorded message by calling 202-2544662 or Autovon 294-4662.

Series 6 A.1 - UT1 DATA. Lists daily values of polar coordinates, correction for seasonal variation, and A.1 - UT1 as observed at USNO and Naval Observatory Time Service Substation (NOTSS), Richmond, FL. The astronomical latitude as observed at each station is also given. (Issued monthly)

Series 7 PRELIMINARY TIMES and COORDINATES of the POLE. Lists general time scale information, values of UT1 UTC predicted two weeks in advance, the Bureau International de l'Heure (BIH) values of UT1 UTC and polar coordinates. Doppler Polar Motion Services, IPMS, and ILS polar coordinates are also listed as they become available. (Issued weekly)

Series 8 TIMES of COINCIDENCE (NULL) EPHEMERIS TABLES for TELEVISION. At present these tables are applicable only for WTTG Washington, D.C., and KTTV Los Angeles, CA. They may be of interest in countries operating on the NTSC system. (Issued annually)

Series 9 TIMES of COINCIDENCE (NULL) EPHEMERIS TABLES and GENERAL INFORMATION for LORAN-C. Individual tables are issued for the master station of each LORAN-C chain. (Issued annually)

1.____Great Lakes	(8970	8.____W. Coast, USA	(9940)
2.____C. Pacific	(4990)	9.____W. Coast, Can	(5990)
3.____Med. Sea	(7990)	A.____N.E., USA	(9960)
4.____N. Atlantic	(7930)	B.____S.E., USA	(7980)
5.____Norwegian Sea	(7970)	C.____Gulf of AK	(7960)
6.____N.W. Pacific	(9970)	D.____E. Coast, Can	(5930)
7.____N. Pacific	(9990)		

Series 10 ASTRONOMICAL PROGRAMS. Includes information pertaining to results, catalogs, papers, etc, concerning the Photographic Zenith Tube (PZT), Danjon Astrolabe, and Dual-Rate Moon Position Camera. (Issued as available)

Frequently this information will be released as a Time Service Announcement Series 14.

Series 11 TIME SERVICE REPORT. Lists general timing information and time differences between coordinated stations and the UTC time system; adopted differences UT1 - UTC and A.1 - UT1; UTC (USNO MEAN) - UTC (USNO MC); UTC (USNO MC) - UTC (BIH); astronomical latitude and UT1 as observed at USNO and NOTSS; polar coordinates and corrections for seasonal and polar (longitude) variations. (Issued annually)

Series 13 PRECISE TIME and TIME INTERVAL PLANNING MEETING. Includes announcement of the meeting held each December in Washington, D.C., the call for papers, and the preliminary program.

Series 14 TIME SERVICE ANNOUNCEMENTS. Includes general information pertaining to time determination, measurement, and dissemination. (Issued as required)

Series 15 BUREAU INTERNATIONAL de l'HEURE CIRCULAR D. Lists Universal Time and coordinates of the pole; emission time of time signals; Universal Time (Coordinated) from LORAN-C and television pulse receptions and independent local atomic time scales (AT_i). This publication is distributed to U.S. addresses only. (Issued monthly)

Series 16 PRECISE TIME TRANSFER REPORT. Lists the time difference UTC (USNO MC) - UTC (reference clock), adjustments to reference clocks and portable clock measurements. The time difference is obtained via communication satellite time transfer, television and/or LORAN-C receptions. (Issued each 20 days)

Series 17 TRANSIT SATELLITE REPORT. Lists the difference UTC (satellite clock) - UTC (USNO MC) and the frequency offset for each of the operational satellites. The information published is received from Naval Astronautics Group, Pt. Mugu, CA. (Issued weekly)

Series 18 WORLD DATA CENTER-A, ROTATION of the EARTH, INFORMATION BULLETIN. Lists proposed times for experiments utilizing modern techniques, such as radio interferometry and laser ranging. When available, preliminary values for polar motion and Universal Time obtained from these techniques are given. (Issued as available)

NOTES:
(1) Past issues of Series 4 are available on microfiche.
(2) Series 6 is available in machine-readable form at the usual exchange ratio of three-to-one.

1.3 TELEPHONE TIME SERVICE

The Time Service Division recently inaugurated a new telephone service for PTTI dissemination. Details were published in Time Service Announcement, Series 14, Number 27, of 23 June 1980. The text of this announcement is given below:

1. For the past several years, the U.S. Naval Observatory (NAVOBSY) has made a limited amount of PTTI data available to users via commercial and military telephone systems. This consisted of voice announcements of the latest Series 5 message (202-254-4662 or AUTOVON 294-4662) and, more recently, a time announcement consisting of voice announcement of time-of-day combined with 1 pps ticks (202-254-4950 or AUTOVON 294-4950). Recently a third telephone system, which provides access to numerous PTTI data files and real time measurement capabilities via a digital communications link, has been inaugurated on a trial basis.

2. The PTTI digital data service provides the latest information available and can be accessed by anyone using a suitably equipped computer terminal. The terminal must be able to operate in a full duplex mode at 300 baud[1] and can be connected to the telephone line through an acoustic coupler or modem which is compatible with Bell 103 modems (or VADIC 3467P). For example, a Texas Instrument (TI) Silent 700 terminal works quite well with the system.

3. Access to the system is by dialing the proper number (commercial 202-254-4080 or AUTOVON 294-4080) and connecting the terminal to the telephone when the PTTI computer answers the call (you will hear a high pitched modem tone). If an acoustical coupler is used, the telephone handset must be firmly

[1]Now compatible at 300 or 1200 baud.

seated in the rubber receptacles. Once the communications link has been established you will receive an acknowledgement beginning with:

* USNO WASHINGTON DC

* Immediately after the acknowledgement, identify yourself by name, location and organization. This identification can be of any length. An inquiry (ENQ) character is sent after the prompt (*). This allows certain terminals (TI Silent 700) to return the identity automatically if it is stored in the answer-back memory (ABM). At this time, messages may be left for NAVOBSY by transmitting them after you receive the prompt (*).

Keying in any of the following key signals, followed by a carriage return (CR), will result in a printout of the data in that file:

@EXP	:	System explanation
@SER 50	:	Series 5 current
@SER 51	:	Series 5 one day previous
@SER 52	:	Series 5 two days previous
to		
@SER 59	:	Series 5 nine days previous
" 70	:	Explanations
" 71	:	UT, X-Y Predictions
@TIME	:	Time of day
@DIR	:	Time Service Directory
@MESS	:	PTTI General Information
@DMESS	:	Special Daily Message
@DLC	:	LORAN-C information
@ONS	:	Omega information
@TRA	:	TRANSIT information/data
@GPS	:	GPS information/data
@DETR	:	DCSC information/data (last PTTI message from Fort Detrick)
@TVK	:	Network TV with greater detail than is available on Series 4

4. Keying in the following provides access to some real time measurements:

@TVM	:	Average of 150 LINE 10 measurements on WTTG Channel 5
@TVN	:	" " 150 " 10 " " NBC " 4
@TVC	:	" " 150 " 10 " " CBS " 9
@TVA	:	" " 150 " 10 " " ABC " 7
@MLO	:	LORAN-C measurements - individual receivers on 9960, 7980, 8970, and 5930 chains. (As these are real-time, single-shot measurements, there may be some slight differences between these values and the Series 4 and 5 values.)

5. Terminate your call by keying in Control D (CNTR D). Otherwise, the program will be unavailable to users until a one-minute timeout elapses. This timeout will also terminate the communications if you are silent for more than one minute.

6. If your request is interrupted for any reason (AUTOVON preemption, for example), your repeat call may not be answered immediately since the computer may be busy compiling your last request. If you get an echo, however, your inquiry is still active.

7. As this is a single channel operation (only one caller can be serviced at a time), best results will be obtained by avoiding the peak telephone and computer traffic hours of 0900-1200 and 1400-1630. If you get poor results, terminate the call and try again. Line quality can vary greatly from call to call (particulary on AUTOVON). In some cases, adjustment of transmit/receive level has been effective.

8. Your comments on this service would be appreciated. If problems are encountered in trying to use the service, call one of the following:

Mr. Mihran Miranian	202-254-4551	or	AUTOVON	294-4551
Mr. Straton Spyropoulos	202-254-4697	or	"	294-4697
Mr. Kenneth Putkovich	202-254-4554	or	"	294-4554
Dr. Gernot M.R. Winkler	202-254-4546	or	"	294-4546

[For technical problems, call Mr. David Chalmers, 202-254-4437 or AUTOVON 294-4437.]

CHAPTER 2

INSTRUCTIONS FOR PRECISE TIME STATION (PTS) OPERATORS

A Precise Time Station (PTS) provides a point for local and transient clock checks both for precise time and for time interval (frequency), and performs a monitor and/or reference function for local transmissions. All of these functions are traceable directly to the U.S. Naval Observatory (NAVOBSY) Master Clock by means of regular portable cesium clock visits or satellite time transfers and indirectly by means of transmissions monitored jointly by the NAVOBSY and the PTS.

PTS are not established by any rigorous or well-defined procedure. In some cases, there are agreements and tasking documentation in existence. In other cases, PTS have been established strictly on the basis of mutual benefit and no formal agreements exist.

The heart of the PTS is the cesium beam frequency standard, which provides the extremely stable frequency that is the reference for all phase measurements and drives clocks for time measurements. To the extent possible, critical systems are provided with dc standby power that automatically takes over in the event of ac power failure.

2.1 PTS FUNCTIONS

PTS are equipped to monitor selected transmissions and to record various types of data. Not all stations are equipped with full PTTI capabilities, but all perform one or more of the following functions.

a. Provide a time and time interval source traceable directly to the DoD Master Clock system. The NAVOBSY Master Clock has been designated the DoD Master Clock to which all DoD PTTI measurements must be referenced.

b. Maintain the time difference between the PTS reference clock and:

1. The NAVOBSY Master Clock via satellite time transfers
2. LORAN-C transmissions via time and frequency comparisons
3. Local TV transmissions via passive monitoring of sync pulses
4. VLF transmissions via frequency comparisons.

c. Monitor and report PTTI radio transmissions, as directed.

d. Monitor and control NAVOBSY PTTI dissemination to local users, as directed, by means of:

1. Portable clocks
2. Microwave links
3. Exchange of TV, VLF, and/or LORAN-C monitor data.

PTTI data may be recorded automatically or manually and have to be reduced several times each day. The data reported to the NAVOBSY are in units of microseconds, as read from the recordings or time interval counter. A special computer format (chapter 15) with internal checks for teletype and clerical errors must be used to report PTTI data for processing by the NAVOBSY. Daily variations in the data will be small unless there are discontinuities in the transmit/receive signals or an abnormality in the transmit/receive system. Since one PTS function is to help determine accurate corrections to transmissions, it is absolutely essential that all discontinuities be fully noted, identified, and reported in the data message to the NAVOBSY.

2.2 OPERATOR INSTRUCTIONS

The following procedures will be used in the operation of a PTS for the NAVOBSY. Detailed procedures for each component of the system can be found in the other chapters of this document and in the equipment operational manuals.

2.2.1 Cesium Beam Frequency Standard Adjustment Regulations

a. Do not adjust the C-field or 1 pps of the cesium standards except by direction from the NAVOBSY.

b. Adjustment messages will give the old and new settings for the C-field dial control or the 6-digit time delay thumbwheel switches and the serial number of the cesium standard to be adjusted. The following are sample adjustment messages (the number following CK is a check number and is double the control number):

INCREASE C-FIELD SETTING OF CS206 FROM 485 CK 970 TO 487 CK 974
CHANGE TIME DELAY SETTING OF CS206 FROM 613987 CK 1227974 TO 614012 CK 1228024

c. Make the change during the next regular working day after receipt of the message, unless notified otherwise.

d. When the adjustment is complete, send a confirming message to the NAVOBSY. The message should list the date/time (ZULU) when the change was made, the serial number of the cesium standard, and the old and new settings of the C-field or time delay switches. The following are sample confirming messages:

051625Z OCT 80

CS206 C-FIELD INCREASED FROM 485 CK 970 TO 487 CK 974

051645Z OCT 80

CS206 TIME DELAY SETTING CHANGED FROM 613987 CK 1227974 TO 614012 CK 1228024

e. If the NAVOBSY does not receive a confirmation within a reasonable time, a follow-up message identified by the word DUPLICATE will be sent. The following are sample duplicate messages:

DUPLICATE. INCREASE C-FIELD SETTING OF CS206 FROM 485 CK 970 TO 487 CK 974

DUPLICATE. CHANGE TIME DELAY SETTING OF CS206 FROM 613987 CK 1227974 TO 614012 CK 1228024

2.2.2 Log Book and Reports

a. Each PTS must keep its cesium standard log book up-to-date by recording the meter readings each week as described in chapter 4.

b. Once each month, the meter, dial, and switch readings should be copied from the log book onto the appropriate NAVOBSY form and air-mailed as follows. No cover letter is required for these reports.

1. Send reports from all Navy stations and Army SATCOM terminals to:

Commanding Officer
U.S. Naval Electronics Systems Engineering Center
PTTI Office, Building 16
U. S. Naval Observatory
34th and Massachusetts Avenue, N.W.
Washington, D.C. 20390

2. Send reports from all Air Force SATCOM terminals to:

AGMC/MLTE
Newark AFS
Newark, Ohio 43055

2.2.3 Equipment Failures

In cases of failure or erratic performance of a cesium standard, a complete list of all circuit check meter readings must be recorded immediately and before taking further action. A report containing the meter readings and describing all abnormal conditions observed should be sent as follows.

a. Send message reports from all Navy stations and Army SATCOM terminals to:

TO NAVELECSYSENGCEN PORTSMOUTH VA
INFO NAVOBSY WASHINGTON DC
(Parent commands, if required)

b. Send message reports from all Air Force SATCOM terminals to:

TO AGMC/MLTE NEWARK AFS OH
INFO NAVOBSY WASHINGTON DC
(Parent commands, if required)

NOTE

The Naval Electronic Systems Engineering Center (NAVELECSYSENGCEN) in Portsmouth, Virginia, provides maintenance support for all U.S. Navy stations and U.S. Army SATCOM terminals. The Aerospace Guidance and Metrology Center (AGMC) provides maintenance support for all U.S. Air Force SATCOM terminals.

NAVELECSYSENGCEN or AGMC will advise on repair action, disposition, or replacement of the defective unit.

2.2.4 Monitoring

Each PTS will monitor one or more of the following systems, as directed.

a. LORAN-C
b. VLF
c. TV
d. Satellite PTTI transfer
e. Microwave link
f. Other.

Instructions and procedures for the operation and reporting of data for the above systems are contained in the remaining chapters of this manual.

NOTE

These instructions and the associated equipment manuals for each component should be kept near the equipment for easy accessibility.

2.2.5 Maintenance

Routine maintenance falls into the following major categories:

a. Providing paper and ink for the recorders as necessary.

b. Checking, cleaning, and exercising the standby dc power supply batteries.

c. Cleaning air filters, changing burned-out lamps, etc.

d. Weekly recording of meter reading into the log book.

In general, breakdowns (the causes of which are not immediately apparent or easy to repair) will be corrected by replacement of the equipment by AGMC or NAVELECSYSENGCEN. This policy was adopted to minimize on-site maintenance and to reduce the necessity for special training in equipment maintenance. AGMC or NAVELECSYSENGCEN should be promptly notified of equipment malfunctions and the replacement equipment required via a priority message. Major local repairs will be authorized by AGMC or NAVELECSYSENGCEN only under extraordinary circumstances.

Any deviations from normal operation (e.g., clock interruptions, LORAN-C receiver requiring relocking, etc) should be reported as follows:

a. Send message reports from all Navy stations and Army SATCOM terminals to:

TO NAVOBSY WASHINGTON DC
INFO NAVELECSYSENGCEN PORTSMOUTH VA
(Parent commands, if required)

b. Send message reports from all Air Force SATCOM terminals to:

TO NAVOBSY WASHINGTON DC
INFO AGMC/MLTE NEWARK AFS OH
(Parent commands, if required)

CAUTION

Do NOT, under any circumstances, adjust the cesium standard C-field, open the phase lock loop, or change the clock time without a directive from NAVOBSY.

2.3 SUMMARY

a. The purposes of the PTS are to provide a precise time and a time interval (frequency) reference standard accurate to within ±1.0 μsec of the NAVOBSY Master Clock and to disseminate precise time and PTTI data to local users.

b. The PTS equipment is highly specialized. The system is set up to minimize data loss due to power interruptions and to minimize the need for maintenance.

c. Data are recorded continually and reported regularly to the NAVOBSY. The reports include any abnormalities observed and explanations necessary to understand and interpret any deviations from normal operation.

d. Adjustments of the cesium clock system that can change time or time interval are performed only by direction of the NAVOBSY.

e. Equipment malfunctions or failures are reported to NAVELECSYSENGCEN or AGMC for instructions or disposition. Field repairs are not authorized except by direction of NAVELECSYSENGCEN or AGMC. Exception: Since the 5062 (O-1695)is field-reparable, Navy ETs are authorized to make modular exchanges and some minor adjustments.

CHAPTER 3

TIME INTERVAL MEASUREMENTS

Time interval measurements are the major means of comparing clocks and disseminating PTTI. The elapsed time between two events, specifically one pulse per second (1 pps) signals generated by clocks or receivers, is measured to determine a time interval. These measurements are made by electronic counters using highly stable frequency standards as references or time bases. The electronic counters, with input circuitry that provides well-defined measurement conditions, provide digital displays of the measured values.

With the advent of frequency standards having stabilities in parts in 10^{-12} to 10^{-14} and digital clocks with pulse jitter in the tens of picoseconds, measurement errors that previously could be ignored as second order have become important. Since the majority of time transfers or synchronizations are made using time interval measurements between two clocks, this discussion is limited to such measurements.

Errors can be classified as either residual or systematic. Residual errors are those that remain after all known systematic errors have been eliminated and are, therefore, the limiting factors in regard to the accuracy of the quantity measured. They can be reduced only by improving the measured system. Systematic errors, on the other hand, are associated with the measuring system or techniques and can be avoided, corrected, or reduced as discussed in the remainder of this chapter.

Systematic errors can be divided into three categories:

a. Gross errors are operator mistakes, including misreading instruments, recording the wrong number, reading the wrong quantity, etc.

b. Instrument errors are problems inherent in the measuring system itself, such as calibration, time base error, synchronous averaging, etc.

c. Measurement errors are caused by physical effects on the measured quantity, such as distorton of the signal, improper impedance matching, transmission problems, etc.

3.1 GENERALIZED MEASURING SYSTEM

Figure 3-1 is a diagram of a general PTTI system. The two clocks produce coherent output signals at repetition rates that have periodic times of coincidence. In the simplest case, they are 1 pps signals. These signals pass through a transmission medium and start a process that measures the relative position of two events in the time domain.

To establish a basis for comparing various systems, a simple means of determining a relative value of uncertainty is necessary. If we assign an uncertainty X_{ij} to each system component in the start and stop channel (figure 3-2) and X_k to the common measuring equipment (figure 3-2), the entire system relative uncertainty, σ, can be expressed as:

$$\sigma = \sqrt{\Sigma X_{ij}^2 + X_k^2}$$

If we combine two or more measurements, using a clock as a transfer standard to determine the relative position in time of two other clocks, the total relative uncertainty can be expressed as:

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2}$$

The uncertainties of each system element shown in figure 3-1 are discussed below. Illustrative values of relative uncertainty are listed in tables 3-1 through 3-5.

3.1.1 Clocks

A clock, in the context of this discussion, is a device that generates a 1 pps signal. Although the purpose of this clock is to maintain a precise time scale over long periods of time, we are concerned here with how the clock behaves over the short period necessary to make time interval measurements. The uncertainties of several different clocks is presented in table 3-2. This shows that the best clocks available have an uncertainty (jitter) of ±0.05 nanoseconds.

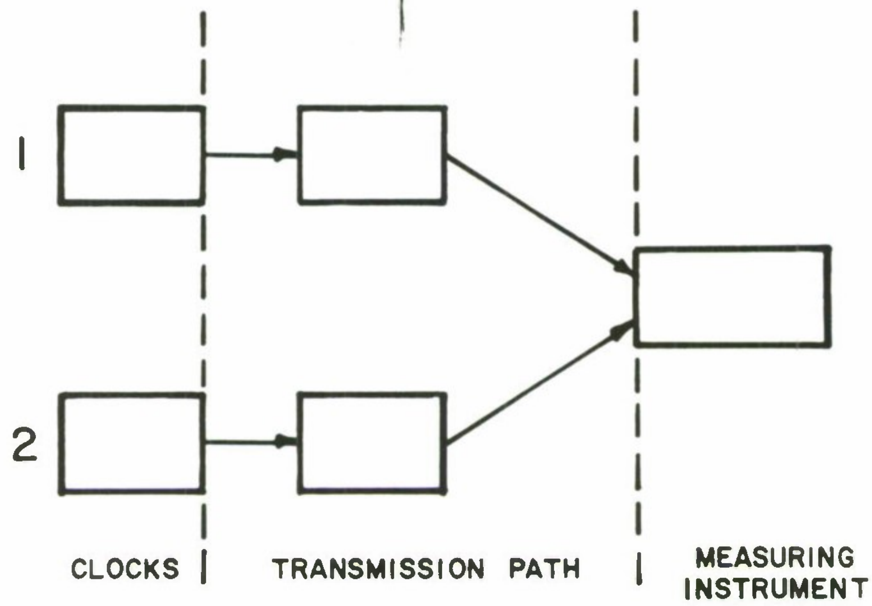


Figure 3-1 Generalized Measuring System

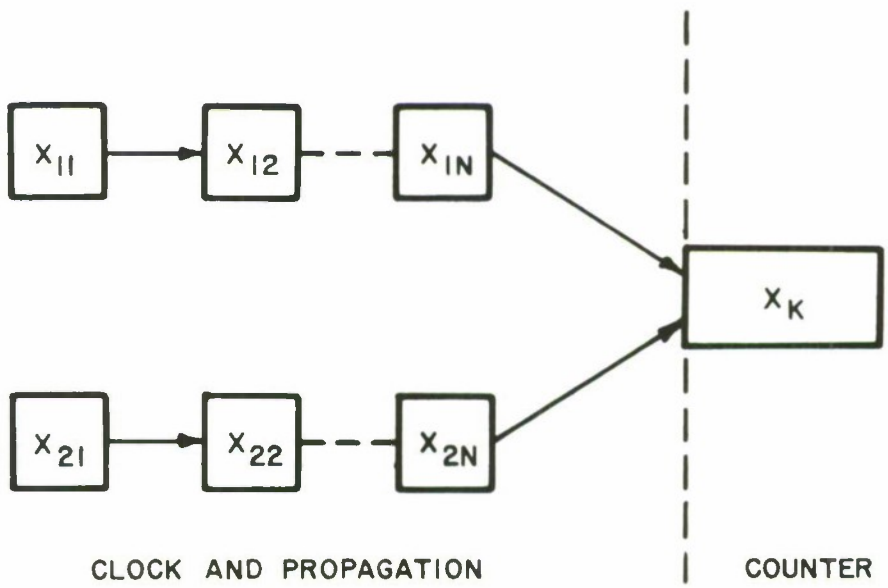


Figure 3-2 Generalized Uncertainties

Table 3-1 Oscillators

TYPE	EXAMPLE	UNCERTAINTY (SEC)
Cesium - High Performance	HP 5061A-004	5×10^{-12}
Cesium - Older	HP 5060	1×10^{-11}
Rubidium	Tracor 204B	1×10^{-11}
Crystal	URQ-10	1×10^{-10}

Table 3-2 Clocks

TYPE	EXAMPLE	UNCERTAINTY (SEC)
Lab Type - Digital	TSI 915 (Nanoclock)	0.05×10^{-9}
Portable - New	HP 5061A-001	1×10^{-9}
Lab Type - Transistor	Tracor 401A	0.1×10^{-6}
Portable - Old	HP 115BR	2×10^{-6}

Table 3-3 Transmission Systems

TYPE	EXAMPLE	ESTIMATED UNCERTAINTY (SEC)
Coaxial Cable - Short	RG 58/U 3 feet	0
Coaxial Cable - Long	RG 58/U 100 feet	0.1×10^{-9}
LF Carrier (Groundwave)	LORAN-C	0.2×10^{-6}
VLF Carrier (Line of Sight)	Television	0.05×10^{-9}
Microwave (Line of Sight)	SATCOM	0.05×10^{-9}

Table 3-4 Time Interval Counters

TYPE	EXAMPLE	UNCERTAINTY (SEC)
Computing	HP 5360	1×10^{-9}
Nanosecond	Eldorado 796	1×10^{-9}
Nanosecond	HP 5345	2×10^{-9}
Ten Nanosecond	Eldorado 784	2×10^{-8}
Ten Nanosecond	HP 5326	0.2×10^{-6}
Microsecond	HP 5245L	0.1×10^{-6}

Table 3-5 Receivers

TYPE	EXAMPLE	UNCERTAINTY (SEC)
LORAN-C Timing	Austron 2000C	0.05×10^{-9}
Television Line 10	Beta 214	0.03×10^{-9}
Microwave	SATCOM	0.1×10^{-9}

Older clocks may have up to ±2 microseconds of jitter. This uncertainty falls into the residual error category because it is inherent to the clock system and can be reduced only by improving the system. In most cases, one has little control over the circumstances that determine the residual uncertainties. Estimates of uncertainty due to clock performance must be accepted and dealt with accordingly.

3.1.2 Transmission Path

When the signal leaves the clock, it immediately begins to degenerate. All classes of systematic uncertainties accumulate along with the residual uncertainties. In the simplest case, the transmission path is a short piece of coaxial cable. In its most complex form, the path may include long cable runs, microwave links, radio transmitters, satellites, and receivers. Here the possibility of gross uncertainty appears, and the possibility of other systematic errors increases in proportion to the complexity of the path. Uncertainties introduced by short coaxial lines are usually insignificant. They become significant when the cables exceed a few meters in length and the delay caused by this length is neglected. Uncertainties introduced by complex transmission paths can amount to hundreds of nanoseconds in fixed propagation path configurations and microseconds in variable path configurations. In all cases, the total uncertainty is the accumulation of uncertainties in each segment of the propagation or transmission path. The majority of measurement uncertainties develop in this area, which is a likely location for gross uncertainties to appear. Table 3-3 gives estimates of transmission path systematic uncertainties for typical transmission media. Many of these uncertainties can be reduced and propagation delays determined with detailed investigation into the transmission processes involved. Initial or one-time measurements are more subject to these errors and the uncertainties must be accounted for in any systems measurement.

3.1.3 Measuring Instrument

When the clock pulse is finally measured, it may be the original pulse virtually undistorted, the original pulse distorted, or a new pulse reconstituted from the transmitted information. The problem is to make a well defined, repeatable measurement with a minimum of measurement and instrument errors and no gross errors. Measurement errors can be reduced by attention to proper transmission line termination, to prevent reflections and distortion due to discontinuities and impedance mismatch. Instrument errors can be reduced by optimizing measurement conditions and giving attention to the details of operation and idiosyncrasies of the instrument being used. Gross errors can be eliminated only by experience and careful attention to each measurement situation.

In general, measuring system uncertainties fall into four areas: ±1 count error, internal trigger error, time base error, and error due to minimum measurable intervals.

a. The ±1 count error is inherent in all digital systems relying on direct counting of the output cycles of a time base gated by the measured signals. Thus, a counter with a 10 MHz time base can have an error of ±0.1 μsec.

b. Internal trigger error is due to the internal noise developed in the start and stop channels and the precision attainable in repeated setting of the trigger level controls. The internal noise error is generally insignificant, but the error due to the settability of the level controls can be quite large and can contribute significant measurement uncertainty.

c. Time base errors are generally insignificant because the internal oscillators of high quality counters are stable in the range from 1×10^{-7} to 1×10^{-9}. Measurement times are generally less than one second, and a highly stable external time base is usually available.

d. Error due to the smallest measurable time interval becomes a problem when the instrument has a very high resolution, but cannot distinguish between closely spaced input pulses. For example, if an instrument has a resolution of 0.01 microsecond, but cannot make a reliable measurement when input pulses are spaced closer than 0.1 microsecond, the error can be as large as the measured value when measuring short intervals. This is generally not a problem in newer counters with high-speed digital logic and improved counting techniques.

3.2 PTTI MEASUREMENT TECHNIQUES

Every effort must be made to reduce the likelihood of gross errors in PTTI measurements. Operator errors are much more likely if measurements are made by personnel with minimal training and less than a full understanding of what is being measured and what the measurement process actually is. Fatigue after long, involved itineraries and the attendant lack of attention to necessary details in procedure also contribute to gross errors when measurements are made in the field. For this reason, standard measurement and reporting procedures must be established and followed. Personnel must understand the measurements if gross errors are to be minimized.

All measurements in any series of measurements should be made using the same equipment, particularly the time interval counter. For example, if for any reason a long cable must be used to measure a clock at a remote site, then the same cable should be used in making all the other measurements. Before making a measurement, the following items must be accomplished:

a. Define the measurement criteria. At what polarity, level, and slope is the measurement to be taken? What is the proper termination impedance?

b. Examine the measured quantity and compare it to prior data, if available, to make certain that the measurement criteria and the measured quantity are consistent. Make a record (photo or sketch) of the measured pulse, annotated with pertinent data such as amplitude, width, rise time, etc. Note any distortion and determine how this might affect the measurement.

The time interval counter must be prepared for the measurement as follows:

a. Select the best available frequency source for a time base.

b. Test or calibrate the counter using internal and/or external signals to test for proper operation and counting.

c. Set input levels, slopes, and slope polarities.

d. Check input lines for proper termination.

When all preparations are completed, connect the two clocks to the time interval counter such that the smaller of the two possible numbers is displayed. Record the measurement as:

Start Clock - Stop Clock = Reading.

The advantages of this procedure are:

a. The result is always the smaller of two possible answers.
b. It is recorded as a positive number.
c. It has less digits to record.
d. The start-stop convention is logical and easily remembered.
e. No arithmetic is involved.
f. The shorter interval results in reduced time base error.

3.3 TYPICAL SYSTEMS

Using the analysis and measurement techniques presented above, we can look at several typical measurement situations encountered in PTTI.

3.3.1 Portable Clocks

The most straightforward and most often encountered high precision time transfer involves portable clock operations. A portable clock is measured against a reference clock, taken to a remote clock against which another measurement is made, and returned to the original reference clock for a final measurement to close the loop (closure). A straight line fit between the initial and final measurements is assumed, so that any difference between the two is apportioned linearly over the time elapsed between the two measurements. The validity of this linear technique may be open to question, but the operator is free to assign his own estimate of this closure error using any criteria desired. Since, for the purposes of this discussion, closure uncertainty is residual, we will only examine the sources of systematic uncertainties.

Assume, for example, that we are synchronizing (measuring) a portable, high performance cesium clock to the NAVOBSY Master Clock using short coaxial cables and a high resolution time interval counter driven by the portable clock. An estimate of the uncertainty contribution of each system component can be determined from tables 3-1 through 3-5. In each case, X represents the uncertainty contributed by each segment of the measuring system.

X_{11} - HP 5061A-004 = 5×10^{-12} = 0.005 nsec
X_{12} - TSI 915 Nanoclock = 0.05 nsec
X_{13} - Short Coax Cable = 0
X_{21} - HP 5061A-004 = 5×10^{-12} = 0.005 nsec
X_{22} - HP 5061A-001 = 1.0 nsec
X_{23} - Short Coax Cable = 0
X_3 - HP 5345 Counter Time Base = 0.005 nsec
Trigger Error = 0.02 nsec
Count Error = 2 nsec

σ_1 - Total Relative Uncertainty = $\sqrt{\Sigma X_{ij}^2 + \Sigma X_k^2} = 2.2 \times 10^{-9}$ sec

If we now perform a typical portable clock operation (figure 3-3), using the portable clock as a transfer standard and measuring another clock having the same specifications as the portable clock, we determine that the second measurement uncertainty is:

$\sigma_2 = 2.5 \times 10^{-9}$ sec

Returning and making a measurement against the Master Clock (assuming zero closure), we find a third uncertainty (the same as the first) of:

$\sigma_3 = 2.2 \times 10^{-9}$ sec

Combine these using:

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2}$$

we find a total uncertainty for a portable clock (pc) measurement of:

$\sigma_{pc} = 4 \times 10^{-9}$ sec

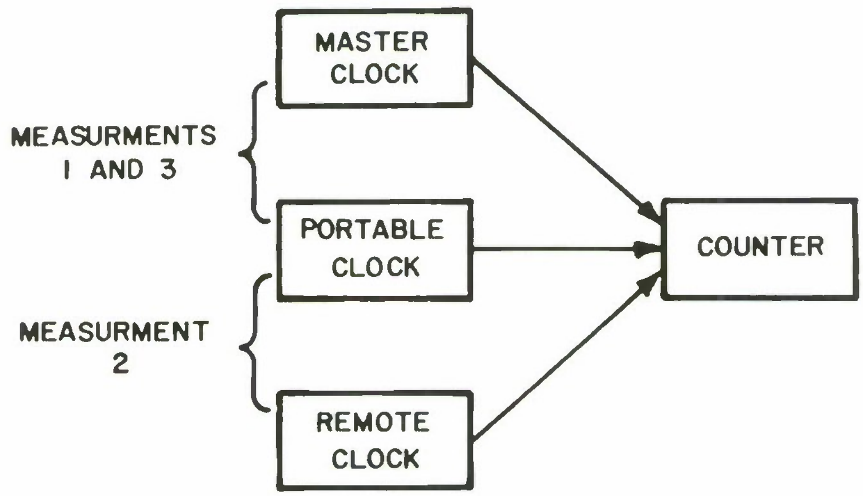


Figure 3-3 Portable Clock Time Transfer

This uncertainty compares favorably with an older, 1965 vintage system (using HP 5060 cesium with 115 BR clocks and a 5245L counter), which would have a much larger error of:

$$\sigma_{pc} = 2.5 \times 10^{-6} \text{ sec}$$

3.3.2 LORAN-C

High precision time transfers using LORAN-C (figure 3-4) can be examined by considering the simple case, for example, of determining the difference between the NAVOBSY Master Clock and another clock within groundwave range of the Great Lakes Chain Master Station at Seneca, New York. This case is analogous to a two-measurement portable clock situation, but adds uncertainties in the transmission path, X_{23}, which includes the transmitter, antennas, receivers, and complex oversea and overland propagation paths. X_{23} can be estimated as follows:

$$X_{23} = \sqrt{X_{pa}^2 + X_{pe}^2 + X_{1c}^2 + X_r^2}$$

where

X_{pa} = propagation anomaly = 0.2 μsec
X_{pe} = propagation path prediction = 0.1 μsec
X_{1c} = transmitted signal uncertainty = 0.02 μsec
X_r = receiving system delay uncertainty = 0.01 μsec

thus

$$X_{23} = 0.23 \times 10^{-6} \text{ sec}$$

Substituting this value into the previous calculation, assuming the same instrumentation at both sites, yields:

$$\sigma_1 = \sigma_2 = 0.23 \times 10^{-6} \text{ sec}$$

$$\sigma_{1c} = \sqrt{\sigma_1^2 + \sigma_2^2} = 0.33 \times 10^{-6} \text{ sec}$$

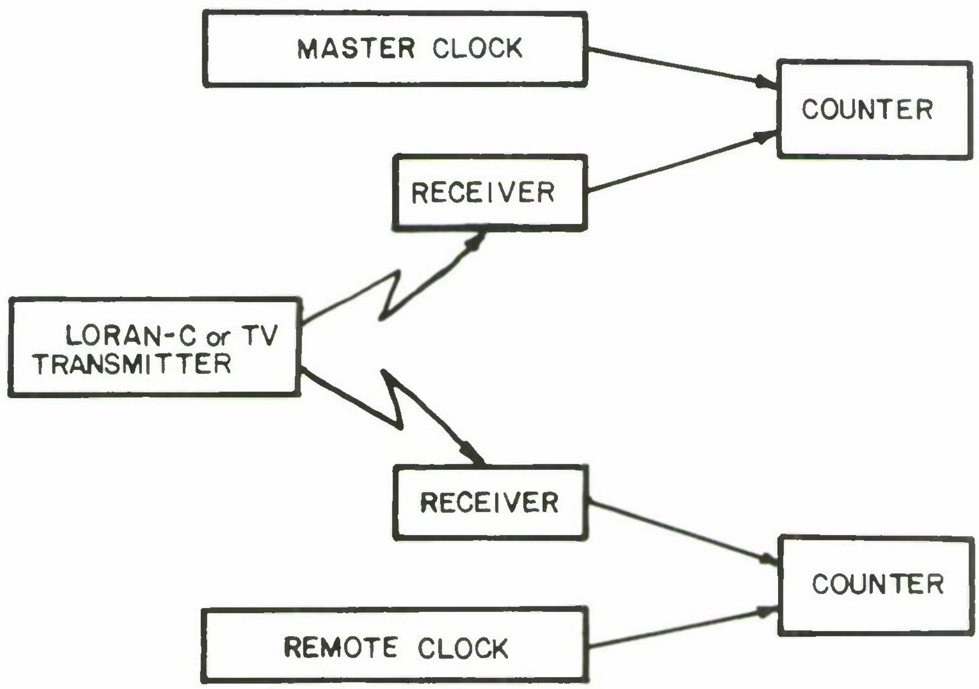


Figure 3-4 LORAN-C or TV Time Transfer

The largest contributor to the total uncertainty is that associated with the transmission path. It should be emphasized that this is the uncertainty associated with a single measurement using conservative values for propagation uncertainties. In most cases, these can be reduced an order of magnitude by portable clock synchronization to verify projected propagation delays, by observing the behavior of the received signal over a period of time, and by tuning the system to reduce the effect of propagation anomalies. If X_{pa} and X_{pe} are reduced by a factor of ten, then:

$X_{23} = 0.03\ \mu sec$
$\sigma_1 = \sigma_2 = 30\ \mu sec$
$\sigma_{1c} = 42\ \mu sec$

3.3.3 Television

The concept of high precision time transfers employing TV is exactly analogous to LORAN-C. The LORAN-C clock in figure 3-4 would be replaced by a TV clock. In a simple case involving, for example, the NAVOBSY and WTTG Channel 5 in Washington, D.C., the transmission path uncertainties are:

$X_{pa} = 0.005\ \mu sec$
$X_{pe} = 0.05\ \mu sec$
$X_{tv} = 0.02\ \mu sec$
$X_r = 0.01\ \mu sec$
$X_{23} = 0.055\ \mu sec$
$\sigma_1 = \sigma_2 = 0.055\ \mu sec$

$$\sigma_{tv} = \sqrt{\sigma_1^2 + \sigma_2^2} = 80\ \mu sec$$

3.3.4 Satellite

Time transfers between two SATCOM satellite terminals are somewhat different from the measurement techniques previously covered. Since this mode of making high precision transfers involves a simultaneous two-way transmission of the time data at high frequencies through a synchronous satellite, the uncertainties due to propagation anomalies and path predictions are reduced. The nature of the transmitted information and the high data rates possible require that the transmitters and receivers be highly stable. The readout of the time transfer data has a ±1 count error at present, which amounts to 0.1 microsecond. This limits the system to an uncertainty of:

$$\sigma_s = 0.14 \times 10^{-6} \text{ sec}$$

Improvement in this case depends on improvement of the measuring equipment. Increasing the resolution to 0.01 microsecond in future systems should result in the uncertainty being reduced to less than:

$$\sigma_s = 20 \times 10^{-9} \text{ sec}$$

3.3.5 Composite System

Examining a typical operational system will give a meaningful estimate of uncertainty in the measurement chain. For example, the Naval Observatory has a Precise Time Reference Station in Hawaii that monitors LORAN-C and determines the difference between the Master Clock and the Central Pacific LORAN-C Chain (4990). The total system consists of the following links and transfer methods:

a. NAVOBSY to SATCOM (Ft. Detrick, MD) - Portable Clock
b. SATCOM (Ft. Detrick, MD) to SATCOM (Hawaii) - Satellite
c. SATCOM (Hawaii) to Reference Station - TV
d. Reference Station to LORAN-C Transmitter - LORAN-C.

Combining the values previously determined for these links (as they presently exist), we find, under ideal conditions:

$$\sigma_{NO\text{-}4990} = \sqrt{\sigma_{pc}^2 + \sigma_s^2 + \sigma_{tv}^2 + \sigma_{lc}^2}$$
$$= 2 \times 10^{-7} \text{ sec}$$

3.4 CONCLUSION

This chapter has discussed high precision time transfer techniques and the uncertainties one can expect in making relative measurements between clocks using these techniques. It must be emphasized that these results can be expected from a competent investigator using state-of-the-art equipment under relatively good operating conditions. Generally, total uncertainties are greater due to less than ideal circumstances and the existence of residual errors that are not easily analyzed and reduced.

CHAPTER 4

CESIUM BEAM FREQUENCY STANDARDS

The Hewlett Packard Models 5061A and 5062C (military designation 0-1695/U or 0-1695A/U) Cesium Beam Frequency Standards are compact, self-contained frequency references that generate a frequency that corresponds closely to time interval standards specified by international agreement. The standards use cesium beam tube resonators to stabilize the output frequencies of quartz oscillators. This is possible because cesium is inherently capable of reproducing a natural invariant resonance.

Solid state components and closed-loop, self-checking control circuits provide a frequency accuracy of ±1 part in 10^{11} in the 5061A and of ±3 parts in 10^{11} in the 5062C. The 5062C, a smaller, more rugged version of the laboratory standard 5061A, can maintain this accuracy for temperatures of -28° C to +65° C and for peak magnetic fields of 2 gauss. Both models have 5 MHz, 1 MHz, and 100 kHz output frequencies.

Both models operate in the same way. In the beam tube, a state-selected beam of Cesium 133 atoms passes through a microwave cavity. When the frequency of the applied microwave magnetic field, derived by multiplying the quartz crystal oscillator frequency, is near the hyperfine transition frequency of Cesium 133 (9,192,631,770 Hz), the microwave signal induces transitions from one hyperfine energy level to another. Atoms that have undergone such transitions are detected by a hot wire ionizer and electron multiplier. The microwave field is phase-modulated at a low frequency of 137 Hz. When the microwave frequency deviates from the center of atomic resonance, the current from the electron multiplier contains a frequency component that is the same as the modulation frequency. The magnitude of this component is proportional to the frequency deviation. The phase indicates whether the microwave signal is above or below the transition frequency. This component is filtered, amplified, and synchronously detected to provide a dc voltage proportional to the frequency deviation. The integral of this dc voltage is used to automatically correct the quartz oscillator frequency.

Not all of the options for frequency standards are available at all sites or on all frequency standards.

4.1 HP MODEL 5061A

4.1.1 HP 5061A Physical Characteristics

4.1.1.1 Front Panel (Figure 4-1)

a. 5 MHz, 1 MHz, 100 kHz output jacks
b. CONTINUOUS OPERATION and ALARM lamps
c. BATTERY lamp

CAUTION

The indicator lamp is a type 327, 28 volt, clear bulb inserted into a red, amber, or green screw-base lens. In case of failure, pull out the bulb from the lens by means of the flange ring on the base of the bulb. Do not throw away the colored lens.

d. 1 pps output, BNC jack
e. Mechanical clock, round face with hour, minute, and second hands; or digital clock with hour, minute, and second displays
f. STANDBY READ button (on instruments with digital clocks)

4.1.1.2 Inner Panel (Figure 4-2)

a. MODE switch
b. BEAM I METER control
c. LOOP GAIN control
d. LOGIC RESET button
e. COARSE OSC FREQUENCY control
f. OSC FREQUENECY x 10^{-10} fine adjustment control
g. 5 MHz FILTER control
h. MOD switch
i. ZEEMAN MOD INPUT jack - for C-Field adjustment
j. M meter jack (optional) - for external circuit check meter
k. DIVIDER MODE switch (on bottom inside of front panel)
l. TIME CONSTANT switch (on bottom inside of front panel)

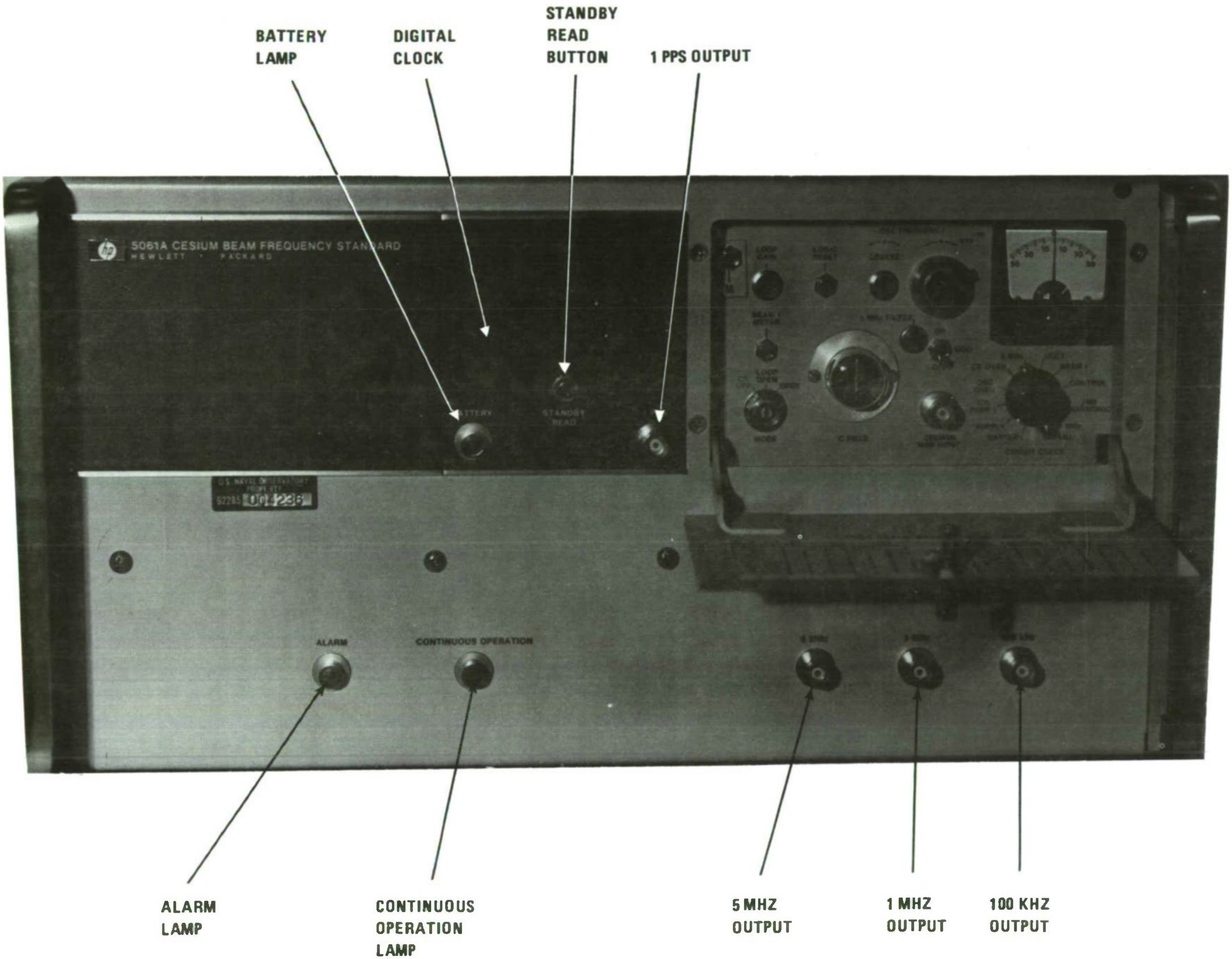


Figure 4-1 HP 5061A Front Panel (Sheet 1 of 2) - Part A Digital Clock

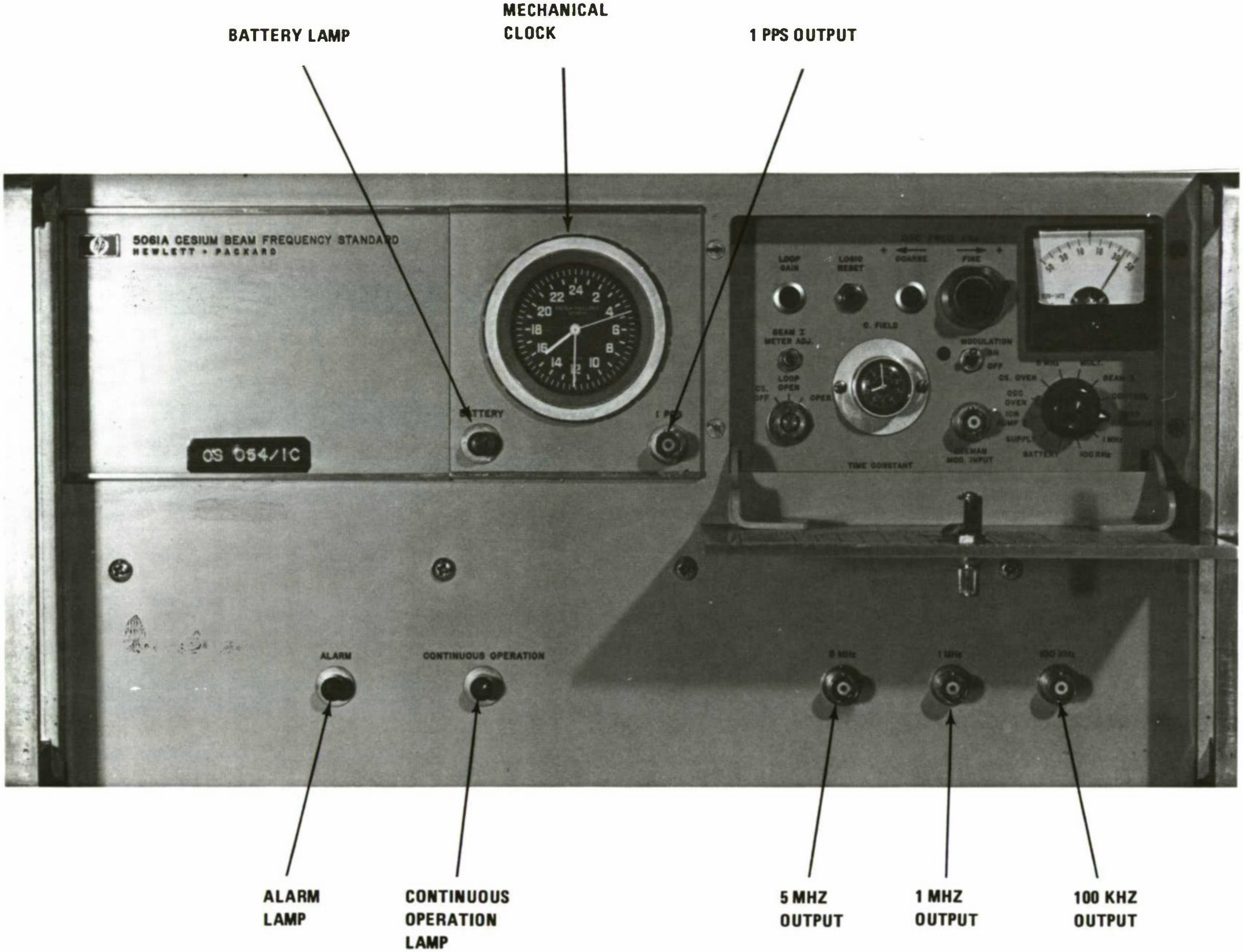


Figure 4-1 HP 5061A Front Panel (Sheet 2 of 2) - Part B Mechanical Clock

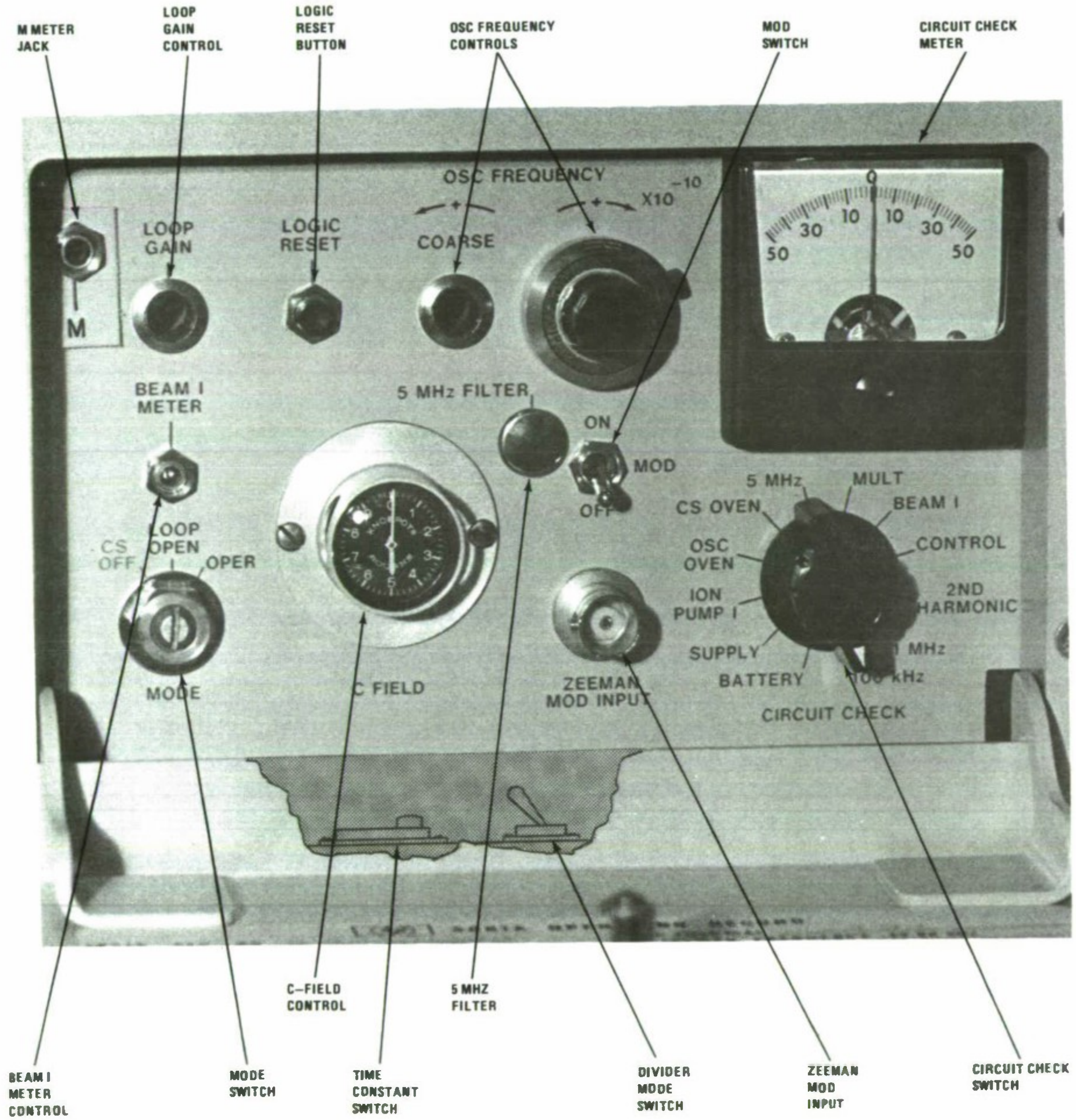


Figure 4-2 HP 5061A Inner Panel

m. C-FIELD control

n. CIRCUIT CHECK meter and switch

Switch positions:

SUPPLY	Regulated dc supply
ION PUMP I	Cesium tube vacuum pump operation
OSC OVEN	Power to oscillator oven
CS OVEN	Power to cesium oven
5 MHz	5 MHz oscillator output level
MULT	Harmonic generator bias
BEAM I	DC beam current from cesium tube
CONTROL	Correction voltage to quartz oscillator
2ND HARMONIC	Second harmonic signal level from cesium tube
1 MHz	1 MHz output signal level
100 kHz	100 kHz output signal level
BATTERY	Battery voltage level

4.1.1.3 Rear Panel (Figure 4-3)

a. 1 PPS output jack
b. 5 MHz, 1 MHz, 100 kHz output jacks
c. CONTROL and SYNTH output jacks
d. SYNC INPUT jack
e. AC line input jack - 3-pin male connector for 115/230 V ac
f. EXT DC input jack - 5-pin male connector for 24 V dc
g. 115/230 V ac line selector switch
h. AC line fuse
i. EXT DC fuse
j. DEGAUSS connector and 1 AMP fuse (high performance option only)

4.1.1.4 Inside Top Cover (Figure 4-4)

a. Set FAST, STOP, and SYNC buttons (mechanical clocks); SYNC button (digital clocks)

b. 0-1 μ SEC TIME DELAY

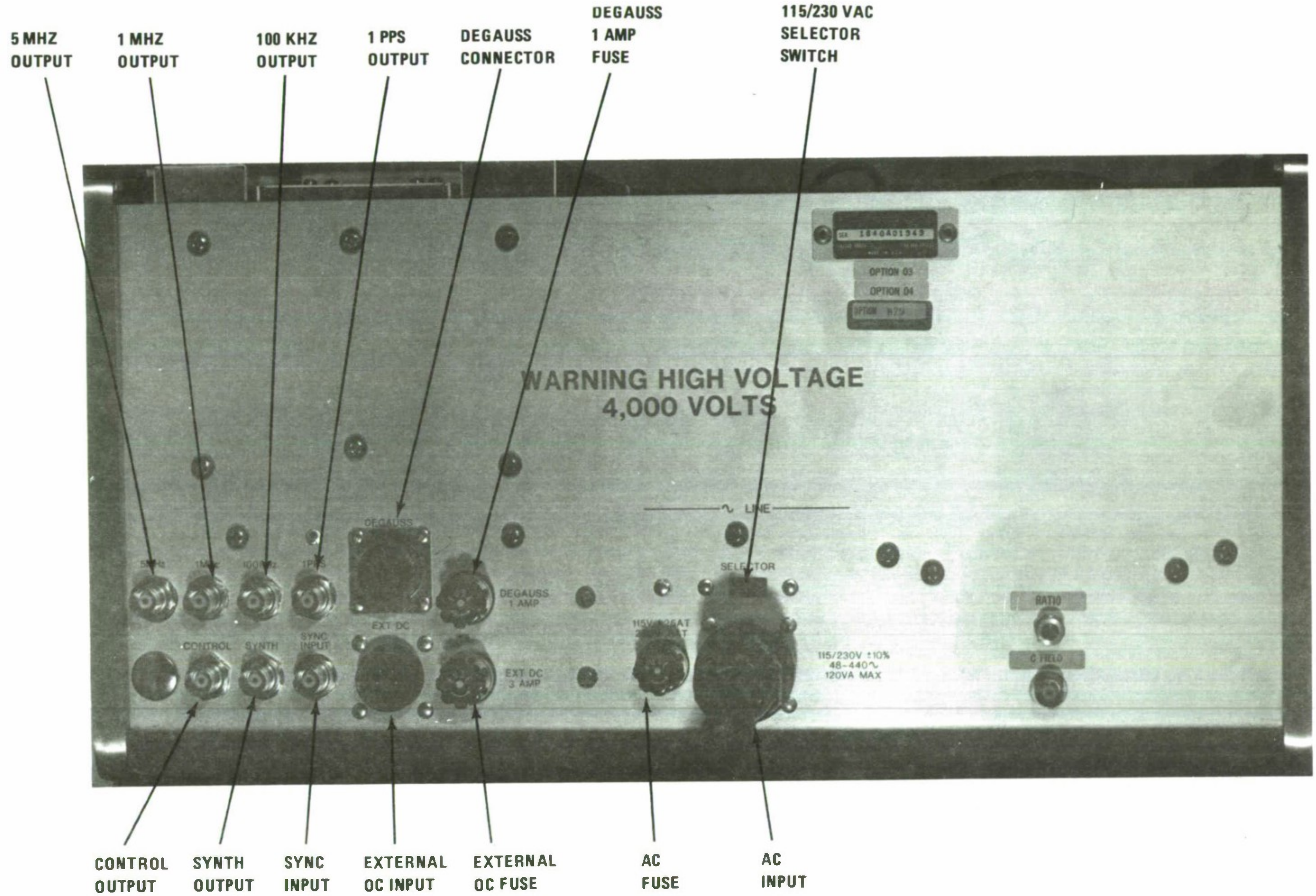


Figure 4-3 HP 5061A Rear Panel

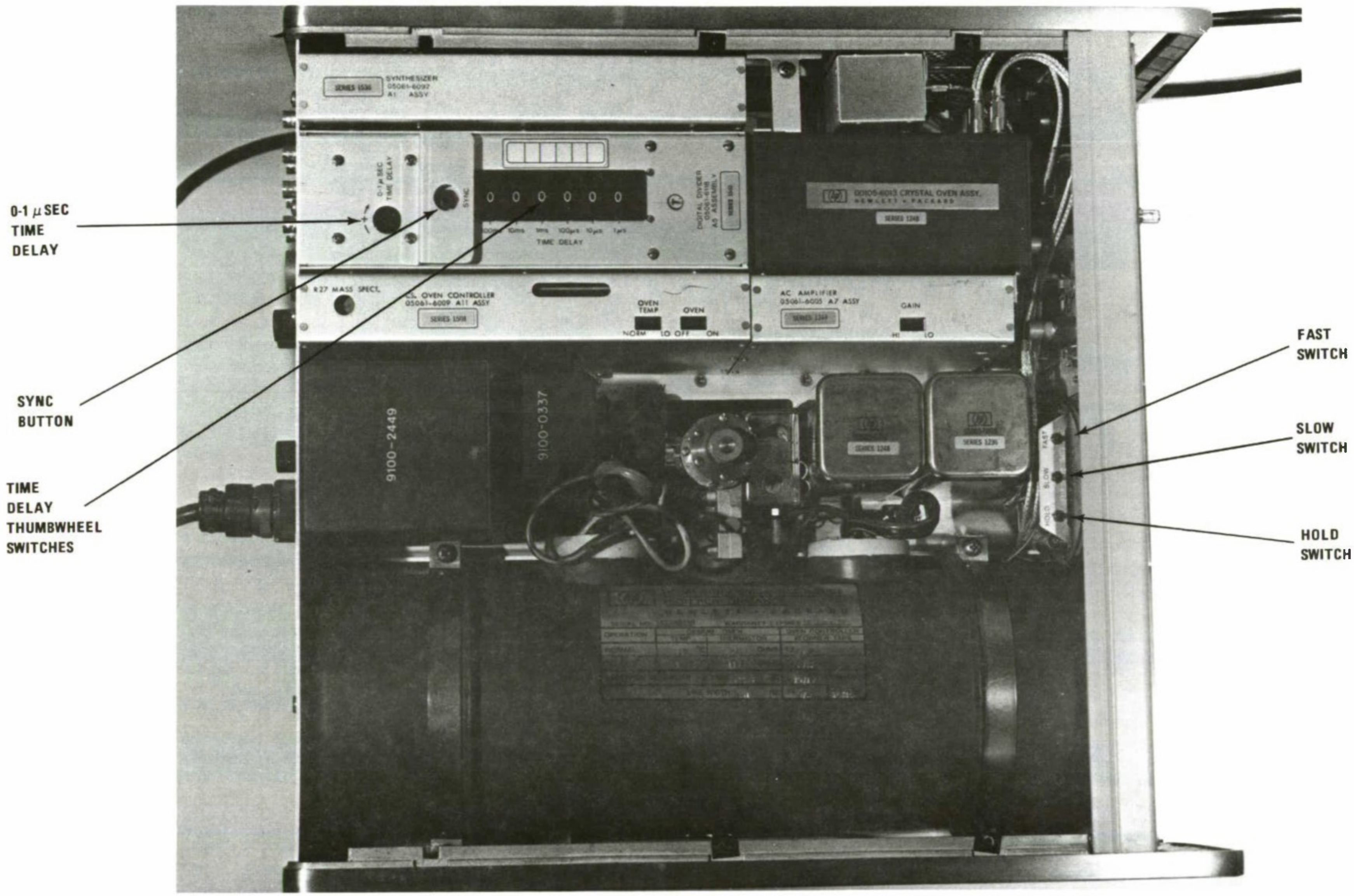


Figure 4-4 HP 5061A Inside Top Cover (Sheet 1 of 2) - Part A Digital Clock

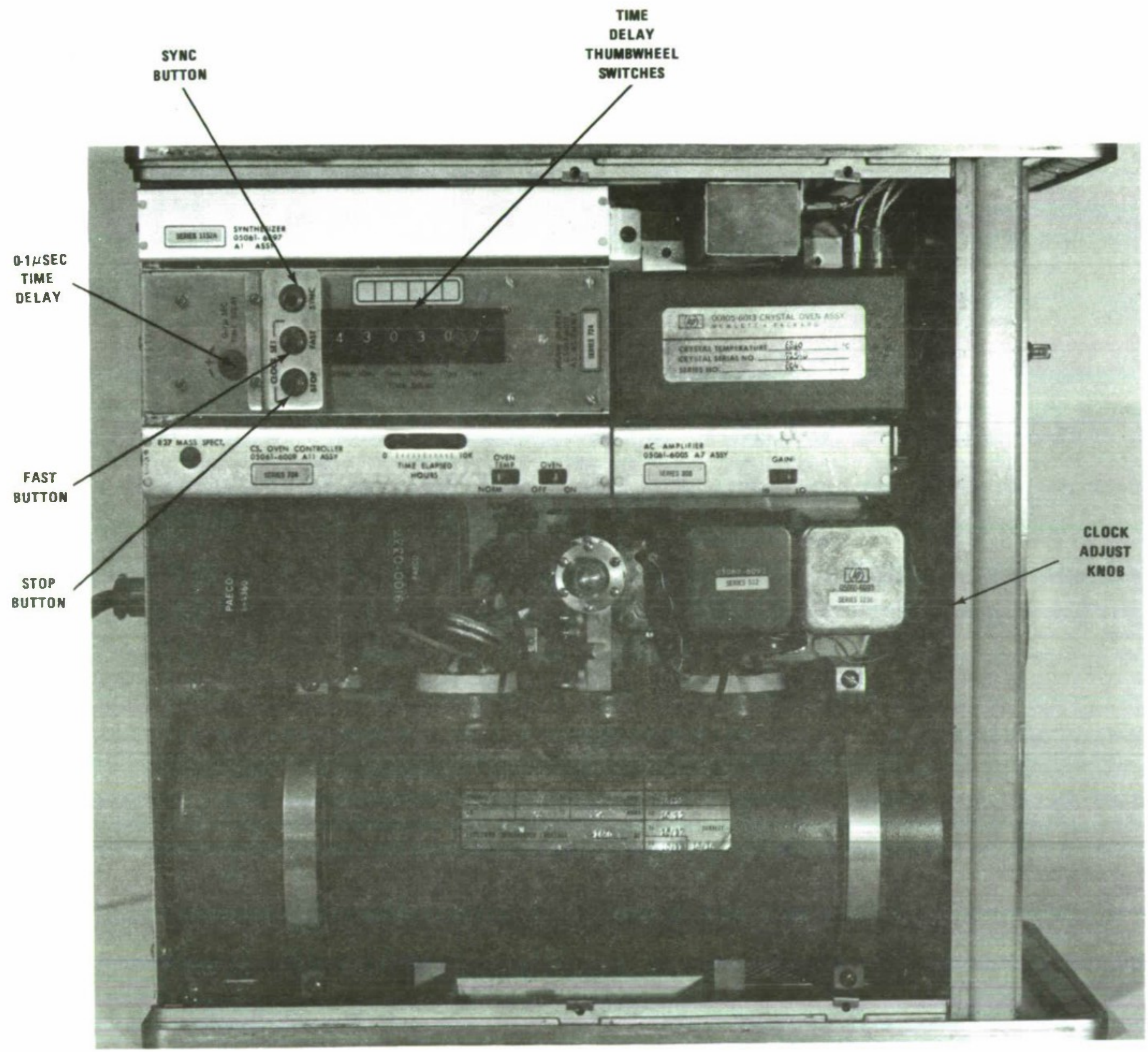


Figure 4-4 HP 5061A Inside Top Cover (Sheet 2 of 2) - Part B Mechanical Clock

c. TIME DELAY thumbwheel switches, 6-bank

d. Mechanical clock adjustment knob (on back of clock movement)

e. SET-SLOW/FAST and HOLD switches (digital clocks)

4.1.1.5 Inside Bottom Cover (Figure 4-5)

a. Switch A2S8 (on front support bracket for A14, A2, and A15 circuit boards) - internal battery disconnect

4.1.2 HP 5061A Unpacking and Inspection

Unpack the 5061A. Inspect all parts for damage (including scratches, dents, broken knobs, etc). If the 5061A is damaged in any way or fails any performance checks after installation, contact NAVELEX immediately for guidance.

4.1.3 HP 5061A Mechanical Mounting

The 5061A is shipped ready to use as a bench instrument. To convert it to rack-mounting, refer to the instructions in section 2, paragraph 2-13 of the Hewlett Packard Cesium Beam Frequency Standard 5061A Operating and Service Manual.

4.1.4 Connecting DC Power Supplies to HP 5061A

a. Ensure that dc power source is turned off.

b. Connect the positive (+) side of the external dc source to pin A of the 5-pin external dc mating connector on the back panel of the HP 5061A.

c. Connect the negative (-) side of the dc source to pin C of the mating connector. Pin C is connected to the 5061A chassis.

d. Turn the dc power source on.

e. The 5061A will operate from the dc source only when ac operating power is not present or has been removed.

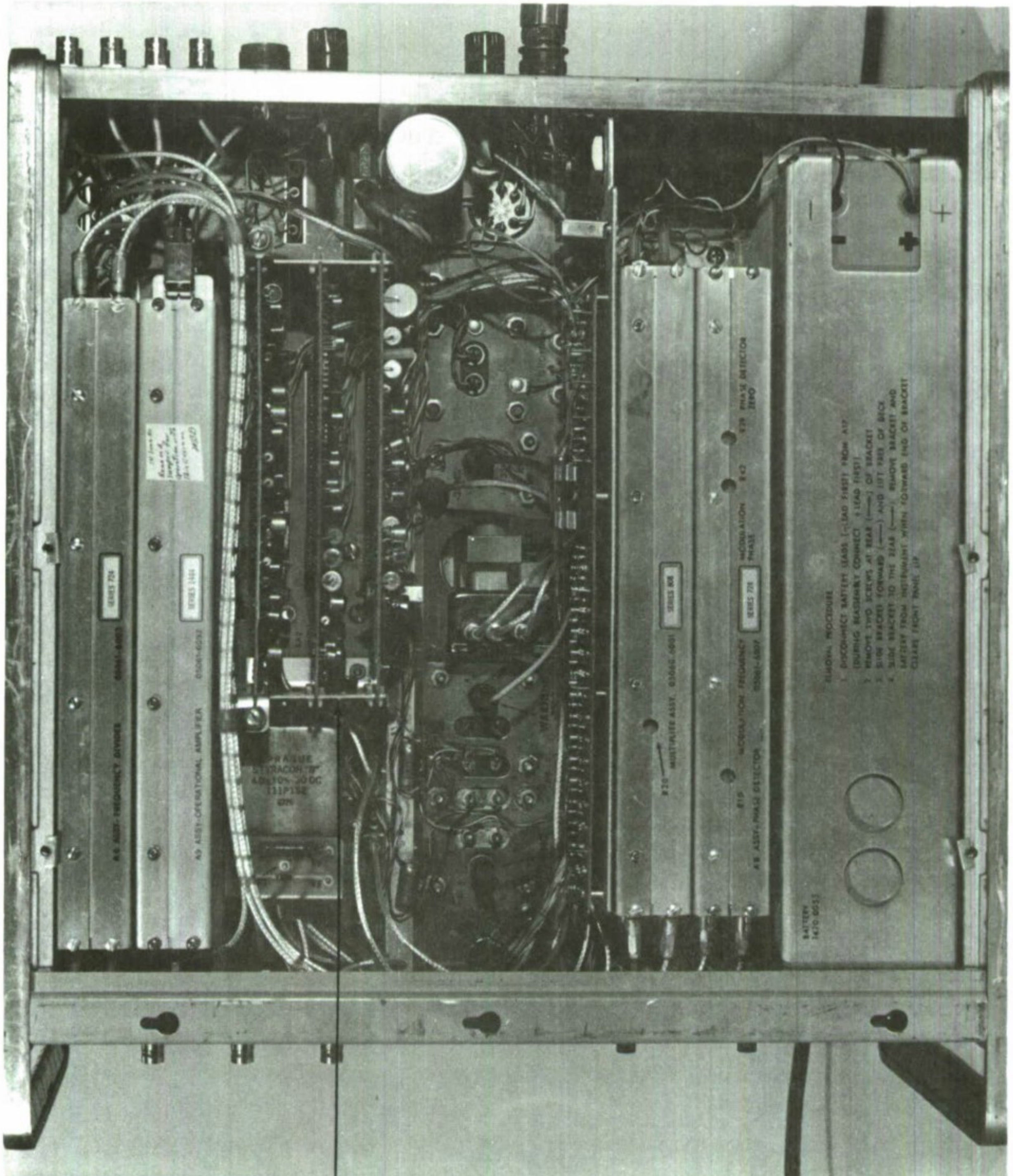


Figure 4-5 HP 5061A Inside Bottom Cover

4.1.5 HP 5061A Turn-On Procedure

a. BEFORE connecting power, ensure the 115/230 V switch on back panel is set to the proper ac voltage. Check your operating line voltage before changing the switch setting.

NOTE

Instruments delivered to a station "hot" via an HP K02-5060A portable clock power supply must have the 115/230 V switch changed to 115 V (if local power is 115 V).

CAUTION

Never change the voltage switch setting with ac power connected. This will damage the instrument.

b. Ensure that the following instrument controls on the front panel are adjusted as follows:

1. MOD switch - ON
2. MODE switch - LOOP OPEN (adjust with screwdriver)

CAUTION

Failure to open loop during warm-up period may cause erratic, abnormal operation and result in a continuous ALARM condition.

3. CIRCUIT CHECK switch - BEAM I
4. TIME CONSTANT switch - SHORT (on bottom inside of front panel)
5. OSC FREQUENCY x 10^{-10} control - 250 (mini-helipot)
6. C-FIELD - dial set by maintenance activity

NOTE

The OSC FREQUENCY x 10^{-10} control and C-FIELD should not be adjusted by field personnel except by direction of NAVOBSY or of the agency responsible for maintenance support.

c. Plug the instrument power cord into an ac power source. Check the instrument for the following:

1. BATTERY light - ON (The battery light will remain on for approximately 14 hours during the internal battery charge cycle.)

2. ALARM light - ON

3. CONTINUOUS OPERATIONS light - OFF

d. Wait a minimum of 45 minutes for the instrument to warm up.

e. Set DIVIDER MODE switch to START. Set MODE switch to OPER.

f. Press LOGIC RESET button on front panel. The CONTINUOUS OPERATION light on the bottom of the front panel will come on and stay on. The ALARM light will be off.

g. The instrument is now operational. If the ALARM light and CONTINUOUS OPERATION light are both on, proceed to step h. If lights are normal, proceed to step i.

h. To turn off the ALARM light, set the CIRCUIT CHECK switch to the CONTROL position and <u>very slowly</u> adjust the OSC FREQUENCY COARSE control with a screwdriver until the meter reads 0. Press the LOGIC RESET button.

NOTE

If the meter indication is to the right, turn clockwise. If the meter indication is to the left, turn counterclockwise.

i. Set the CIRCUIT CHECK meter switch to each of the 12 positions and record the readings observed on the meter into the instrument log book. See 4.1.10 for acceptable meter readings.

<u>CAUTION</u>

Set the CIRCUIT CHECK switch to CS OVEN. The meter reading should be between 5 and 35. If the reading is higher than 35 for more than 15 minutes at any time, <u>remove power immediately</u>. Operation for a longer period at this level can damage the cesium beam tube.

j. Record the following dial readings and switch settings into the log book:

1. C-FIELD

2. OSC FREQUENCY adjust x 10^{-10}

3. MOD
4. MODE
5. TIME CONSTANT

4.1.6 HP 5061A Warning Lights

On rare occasions, when external power is disrupted or lost momentarily, the ALARM lamp will light and the control meter will be pegged to the extreme right or left. This indicates a problem in the control circuit. To correct this condition, rotate the MODE switch from OPER to LOOP OPEN, then rotate it back to OPER. The ALARM light should go off, then press the LOGIC RESET button. The CONTINUOUS OPERATION lamp will light and the instrument will be operational and normal.

4.1.7 HP 5061A Clock Synchronization

If an electrically compatible sync pulse is available from a reference source, it may be used to automatically synchronize the 5061A 1 pps output to the reference source. If no compatible sync pulse is available, the 5061A may be manually synchronized.

4.1.7.1 Automatic Synchronization

a. Remove the top cover of the cesium standard.

b. Set the 6 thumbwheel switches on the TIME DELAY unit to 000000.

c. Connect the reference 1 pps to the 5061A rear panel SYNC INPUT jack. The reference input pulse must be at least +5 V with a rise time of less than 0.5 microsecond.

d. Press the SYNC button on the clock module and hold it down for at least 1 second. The next 1 pps of the 5061A will be synchronized to the reference 1 pps and delayed by 9 to 11 microseconds. Any additional offset may be made by adjusting the 6 thumbwheel switches.

e. If the clock has a mechanical movement, go to f. If it has an electronic movement, go to h.

f. Using the knob on the back of the clock movement, set the HOURS and MINUTES hands, then replace the top cover.

g. Open the access door in the top cover. Using the FAST button to speed up the SECOND hand, or the STOP button to stop the SECOND hand, set the clock to the proper second.

NOTE

The electronic displays do not always self-start. Operating the buttons/switches on the back of the display board usually starts the clock.

h. Advance the clock display (using SET, SLOW/FAST switches) to 10 or 15 seconds ahead of the reference clock and press and hold the HOLD button.

i. When the reference clock displays the same time as that on the clock being set, release the HOLD button.

j. Check to see if the two displays are the same. If they are, secure the clock cover. If they are not, go back to e and repeat the procedure.

CAUTION

When the clock TIME DELAY select thumbwheel switches go from all zeros to all nines or vice versa, the time on the clock display may jump by 1 second.

4.1.7.2 Manual Synchronization

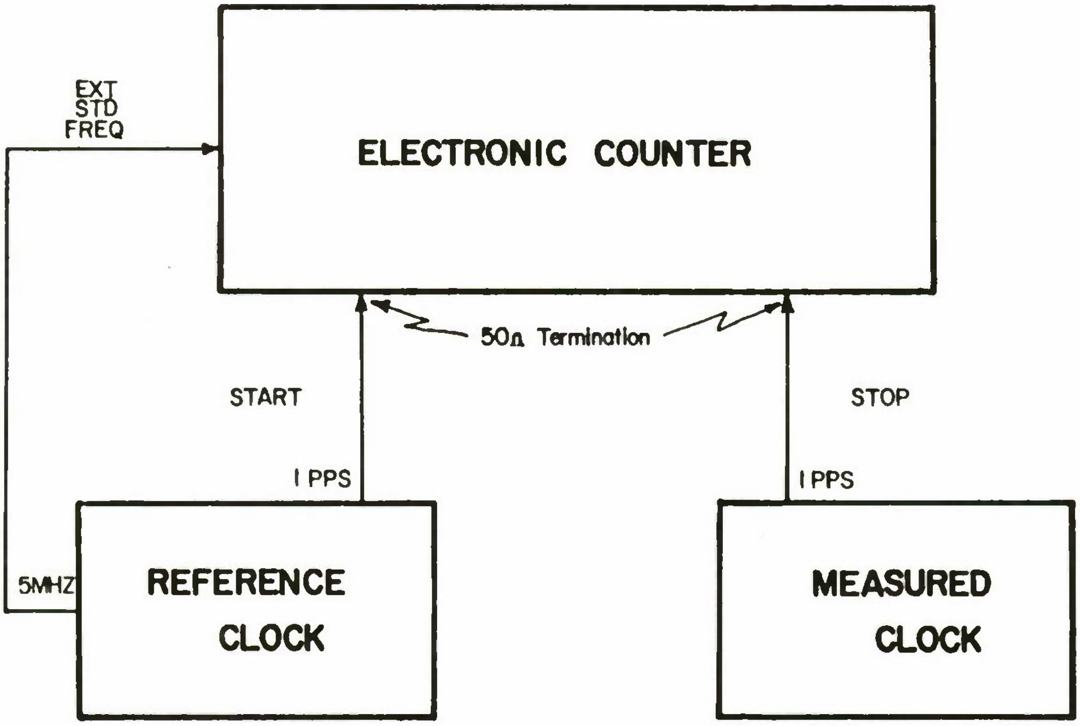
The 5061A 1 pps output can be manually synchronized with a reference source, using either an oscilloscope or a time interval counter, by performing the following procedure.

a. Remove the top cover of the cesium standard.

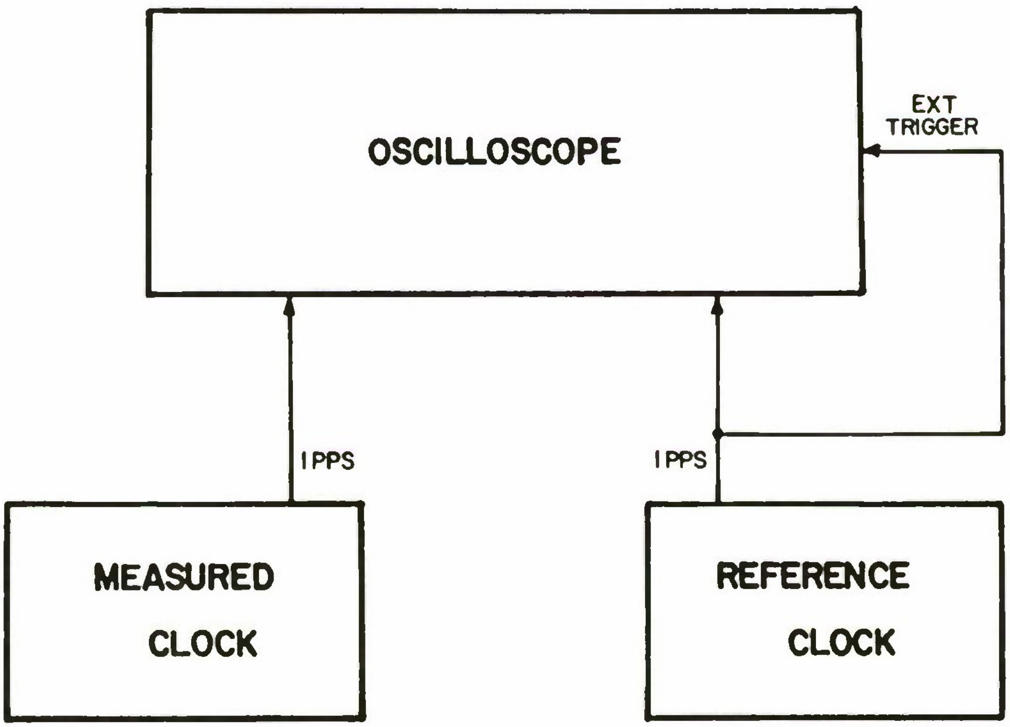
b. Set the 6 thumbwheel switches to 999999.

c. Connect the 5061A as shown in figure 4-6. When using the time interval counter, terminate the 5061A 1 pps output cable with a 50-ohm load to minimize pulse ringing.

d. When using a time interval counter, set the counter time base for best resolution. Set the time interval unit to trigger on the leading edges of the



A. Time Interval Counter



B. Oscilloscope

Figure 4-6 1 PPS Manual Synchronization

two input pulses. The leading edge of the 5061A output is the positive-going edge.

e. When using an oscilloscope, set the oscilloscope controls to display both pulses. Ensure that the oscilloscope is set to EXTERNAL SYNC.

f. Set the 6 thumbwheel switches for coincidence, or for the desired offset between the 5061A 1 pps and the reference source clock pulse.

g. Set time of day using procedures in paragraph 4.1.7.1f-j.

4.1.8 HP 5061A Internal Standby Battery

The HP 5061A is equipped with an internal, standby battery, rated to provide 30 minutes of clock operation after the loss of primary ac power. The BATTERY lamp will be lit when battery power, in any amount, is available for use. It does not indicate how much power is available or if the battery is currently in use.

Battery recharge is automatic when external power is available. The recharge time is variable depending on the ambient temperature and the original charge-state of the battery. The recharge time for the 5061A should be about 22 hours.

When the instrument is operating on internal battery power, the digital clock display will be off. To read the display, press STANDBY READ. Extensive use of the STANDBY READ button will significantly decrease the available power.

4.1.8.1 Internal Standby Battery Problems

It has been found that internal standby battery power often lasts for significantly and unpredictably shorter periods than expected. The battery lights and meter readings cannot be relied on as true indicators of the available power capacity.

The operator should be aware that there may be less time available on standby power than the indicators may show. The time available can vary from as much as the full rated time to as little as less than a minute. The indicators will only tell the operator when there is zero time available.

When external power is disconnected from the instrument, it will automatically switch to internal battery power. If there is insufficient power, or if the battery system is defective, the instrument will simply stop operating.

When external power is reapplied, the instrument may make a chattering noise. This is the low voltage sensoring relay. If the chattering stops within 15 minutes, the battery will recharge normally. If the chattering continues for more than 15 minutes, it is an indication that the battery pack is defective and must be replaced. Remove the battery and continue instrument operation on external power. Contact NAVOBSY or NAVELEX for guidance.

4.1.8.2 HP 5061A Internal Standby Battery Periodic Maintenance

CAUTION

As this procedure can cause the clock to stop if impropery done, it should be carried out only under direction from NAVOBSY.

The 5061A internal standby battery should be "exercised" every 60 days by performing the following procedure.

a. Disconnect the instrument ac power cord from its line source. This operates the 5061A on internal battery power. The front panel BATTERY light will flash on and off. The CONTINUOUS OPERATION light will remain on.

b. Reconnect the ac power cord after 15 to 20 minutes. The BATTERY light will remain on until the battery is recharged. This will take about ten times as long as the time the battery was used.

4.1.8.3 HP 5061A Internal Standby Battery Removal and Replacement

a. Turn off all operating power before removing battery.

b. Remove the instrument bottom cover and press the battery disconnect switch on the circuit board front support bracket.

c. Remove the battery charger assembly. The instrument can operate on external power without this assembly.

d. The battery charger assembly can be reinstalled by reversing the above procedure. No adjustments are necessary.

4.1.9 Cesium Frequency Standard C-Field Control

The C-Field Control reading consists of three digits, as shown in figure 4-7.

a. The first digit is the last number on the dial passed by the small hand.

b. The second digit is the last number on the dial passed by the large hand.

c. There are ten units between every two numbers on the dial. Every other unit is marked. The third digit is the number of units between the large hand and the last number that it passed.

4.1.10 HP 5061A Weekly Checks and Monthly Reports

Once each week, set the CIRCUIT CHECK switch to each of the 12 positions and record the meter readings into the instrument log book. All meter indications are right of zero, except the CONTROL voltage, which may be either right or left of the center position. The following meter reading limits are acceptable for field operations.

Switch Position	Normal Meter Reading
BATTERY	0 with no battery; 35-50 with battery
SUPPLY	35-45
ION PUMP I	0-15 (increases with age of cesium tube)
OSC OVEN	20-45 (changes with temperature)
CS OVEN	5-35 (changes with temperature)
5 MHz	35-45 (no load)
MULT	35-45

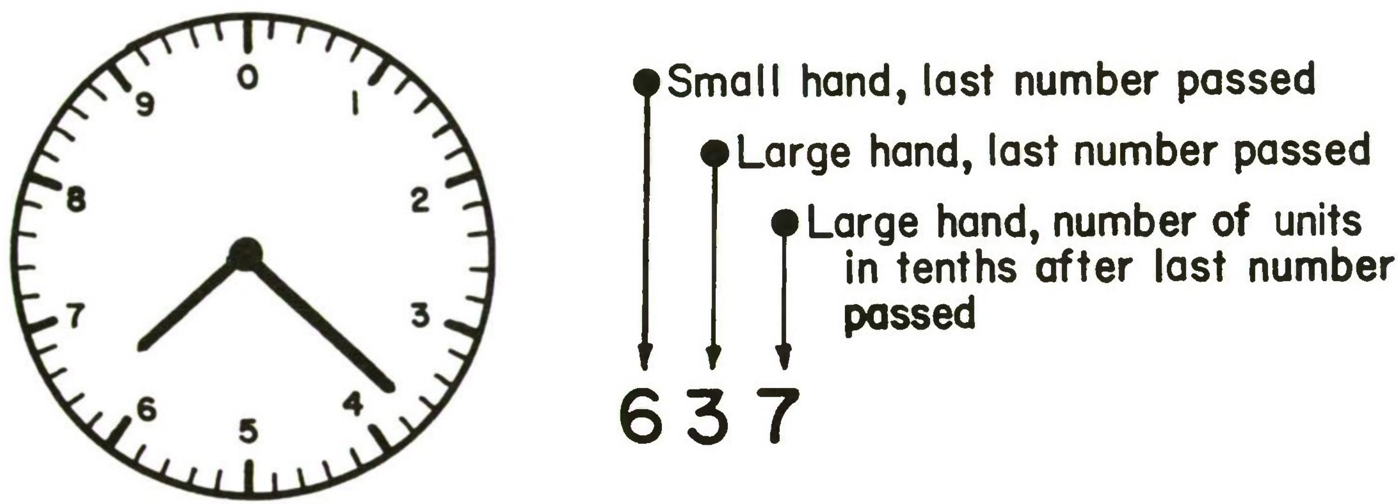


Figure 4-7 C-Field Control Reading

Switch Position	Normal Meter Reading
BEAM I (operator adjustable)	15-20
CONTROL (operator adjustable)	0 (less than 5 right or 5 left)
2ND HARMONIC (operator adjustable)	20-45
1 MHz	35-45 (no load)
100 kHz	25-45 (no load)

In addition to the meter readings, record the following dial readings and switch settings.

C-FIELD	650-750 (standard option)
	475-525 (high performance option)
OSC FREQ ADJ (x 10^{-10})	250
MOD	ON
MODE	OPER
TIME CONSTANT	SHORT

There are three conditions that require operator adjustment after the weekly readings are recorded:

a. The BEAM I reading is below 15.

b. The CONTROL reading exceeds 10 right or 10 left of zero.

c. The 2ND HARMONIC reading is below 35.

When any of the above occur, the operator will make the appropriate adjustment described below.

a. Set the CIRCUIT CHECK switch to the CONTROL position and <u>very slowly</u> adjust the OSC FREQUENCY COARSE control with a screwdriver until the meter reads 0.

b. Set the CIRCUIT CHECK switch to the 2ND HARMONIC position and <u>slowly</u> adjust the LOOP GAIN with a screwdriver until the meter reads 45.

c. Set the CIRCUIT CHECK switch to the BEAM I position and <u>slowly</u> adjust the BEAM I METER with a screwdriver until the meter reads 30.

NOTE

If the meter indication is to the right, turn clockwise. If the meter indication is to the left, turn counterclockwise. The ALARM lamp may light momentarily if adjustment is too rapid.

d. When the adjustment is completed, press the LOGIC RESET button to light the CONTINUOUS OPERATION lamp.

e. Enter a brief summary of the adjustments made and the new meter readings in the REMARKS column of the instrument log book and in the Monthly Report form.

All meter and dial readings and switch settings should be recorded monthly on the appropriate form (figure 4-8) and mailed as follows.

All Navy and Army SATCOM Stations

PTTI Office Building 16
U.S. Naval Observatory
34th and Massachusetts Avenues, N.W.
Washington, D.C. 20390

All Air Force SATCOM Stations

AGMC/MANE
Newark AFS
Newark, OH 43055

A cover letter for these reports is not required. Station personnel are encouraged to include legible comments, suggestions, or questions, pertaining to PTTI, on a separate sheet with the monthly report form.

4.1.11 Cesium Frequency Standard Turn-Off Procedures

Cesium Beam Frequency Standards that have internal batteries will continue to operate on internal battery power when external ac and dc power are removed.

Station ________________________ Date ________________________

Reporting Period (Dates) ________________________ to ________________________

Cesium Beam Frequency Standard – Serial No. ________________________

Prior to recording the readings, check the following:

( ) ON CONTINUOUS OPERATIONS lamp

( ) OFF ALARM lamp

( ) OFF BATTERY lamp

( ) ON MOD switch

( ) Operating Mechanical/Digital clock

( ) OPER MODE switch

( ) SHORT TIME CONSTANT switch

( ) START DIVIDER START switch

Dial Settings:

C-FIELD ________________________ TIME DELAY ________________________

OSC FREQUENCY ________________________

CIRCUIT CHECK meter readings:

BATTERY ________________________ MULT ________________________

SUPPLY ________________________ BEAM I ________________________

ION PUMP I ________________________ CONTROL ________________________

OSC OVEN ________________________ 2ND HARMONIC ________________________

CS OVEN ________________________ 1 MHz ________________________

5 MHz ________________________ 100 KHz ________________________

Remarks: ____

____

____

MAIL TO: Commanding Officer
U.S. Naval Electronics Systems
Engineering Center, Portsmouth
PTTI Office Bldg. 16
U.S. Naval Observatory
34th Street and Massachusetts Ave., N.W.
Washington, D.C. 20390

Telephone: (202) 254-4021
Autovon: 294-4021

Figure 4-8 HP 5061A Monthly Report

The following procedure should be performed to turn units off.

a. Set MODE switch to LOOP OPEN.

b. Remove external ac and dc power.

c. Let the unit run until the internal battery discharges down to its turn-off point.

4.2 HP MODEL 5062C

4.2.1 HP 5062C Physical Characteristics

4.2.1.1 Front Panel (Figure 4-9)

a. 5 MHz, 1 MHz, 100 kHz output jacks with BNC connectors
b. CONTINUOUS OPERATION and ALARM lamps
c. AC POWER and DC POWER lamps
d. Clock and accessories, including:
   - Display - a 6-digit, 24-hour LED that displays hours, minutes, and seconds
   - HOURS, MINUTES, and SECONDS set buttons
   - STANDBY DISPLAY button
   - SYNC jack with BNC connector
   - 1 PPS jack with BNC connector
e. BATTERY POWER and FAST CHARGE lamps

4.2.1.2 Inner Panel (Figure 4-10)

a. OSC FREQ - provides a frequency adjustment of 1×10^{-6}
b. ZEEMAN MOD FREQ - 70.40 kHz ± 50 Hz for C-Field adjustment
c. MODE switch
d. C-FIELD control
e. EXT METER - for external voltmeter or ammeter
f. LOGIC RESET button
g. MODULATION switch
h. BEAM I ADJ

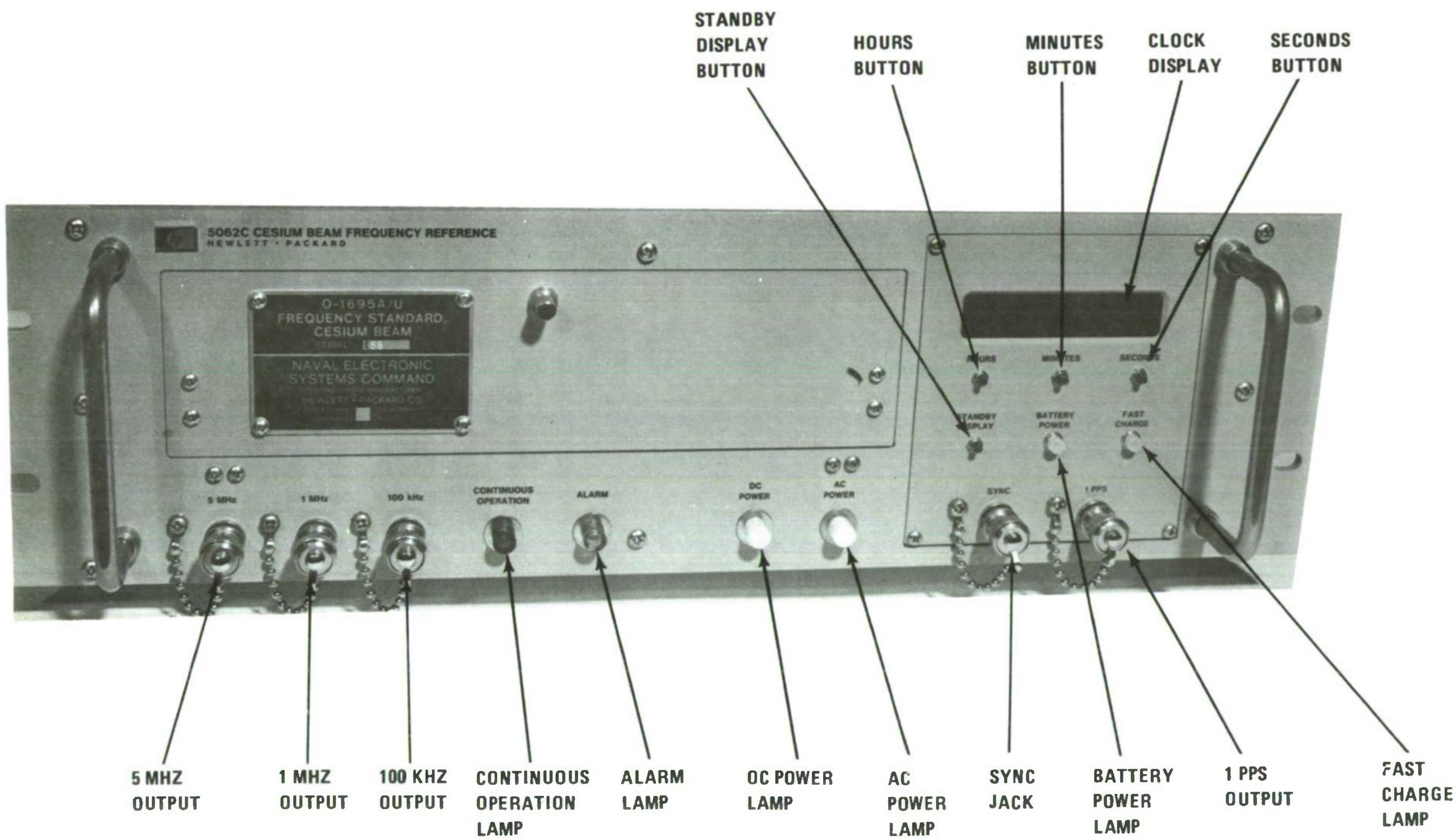


Figure 4-9 HP 5062C Front Panel

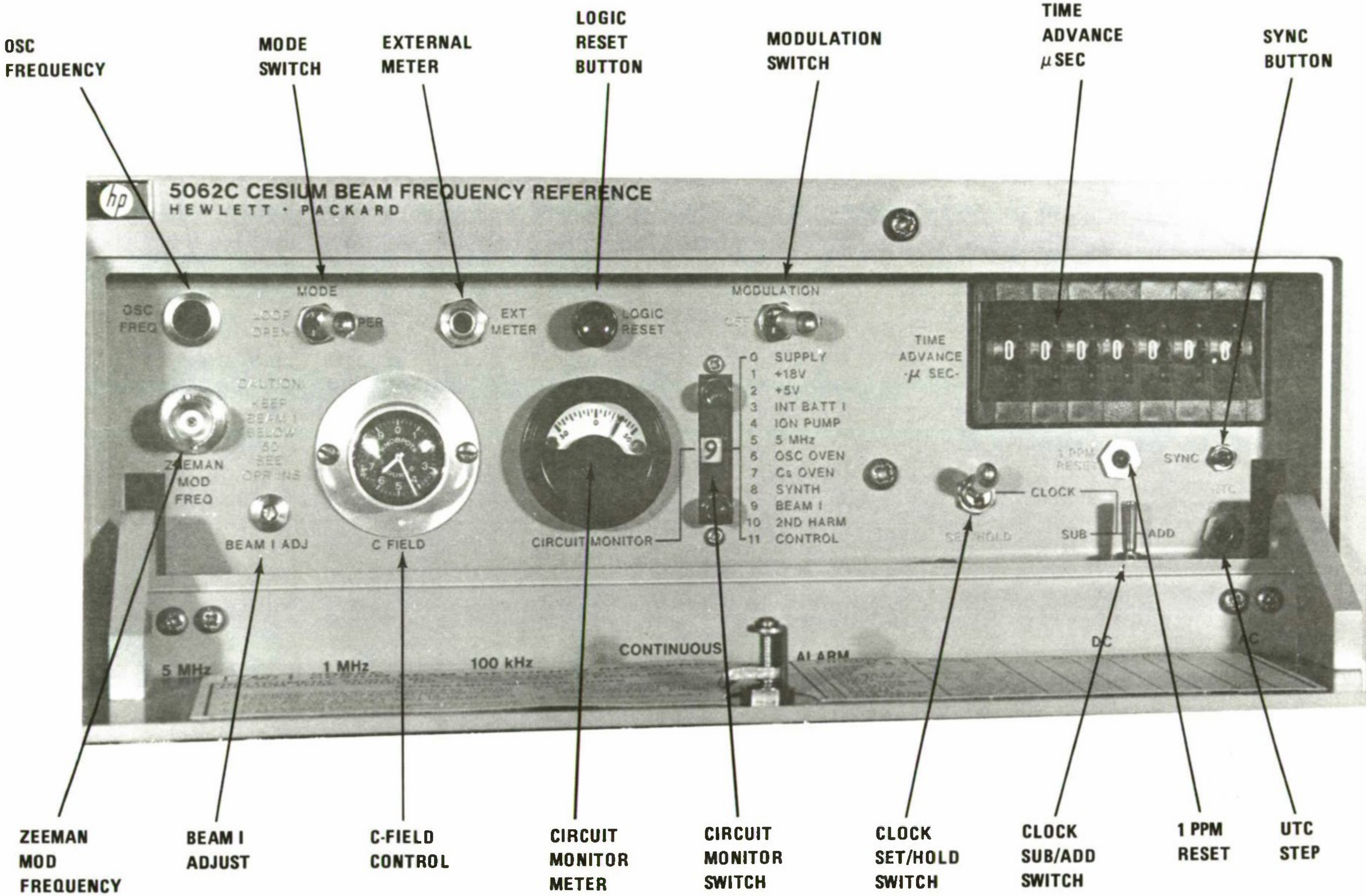


Figure 4-10 HP 5062C Inner Panel

i. CIRCUIT MONITOR meter and switch

Switch positions:

0	Supply	Unregulated dc supply
1	+18V	+18V regulated supply
2	+5V	+5V regulated supply
3	INT BATT I	Battery charge/discharge current
4	ION PUMP	Cesium tube vacuum pump operation
5	5 MHz	5 MHz oscillator output level
6	OSC OVEN	Power to oscillator oven
7	CS OVEN	Power to cesium oven
8	SYNTH	Synthesizer alarm circuit
9	BEAM I	DC beam current from cesium tube
10	2ND HARM	Second harmonic signal level from cesium tube
11	CONTROL	Correction voltage to quartz oscillator

j. Clock controls, including:

TIME ADVANCE μSEC - 7-bank, 10-digit thumbwheel switch

CLOCK SET/HOLD

CLOCK SUB/ADD

SYNC

UTC STEP

1 PPM RESET

4.2.1.3 Rear Panel (Figure 4-11)

a. 1 ppm outputs - Pin A is the signal; pin B is the signal return.

b. 5 MHz signal - Pin A is the signal; pin C is the signal return.

c. 5 MHz signal - Pin 1 is the signal; pin 2 is the signal return; pin 5 is not used. For remaining pins, see d below.

d. TIMING FAULT - Pin 3 is the timing fault signal; pin 4 is the signal ground; pin 5 is not used.

e. BATTERY DROP OUT button

f. LINE VOLTAGE SELECTOR switch

g. POWER ON/OFF switch

h. BATTERY FUSE for internal battery pack

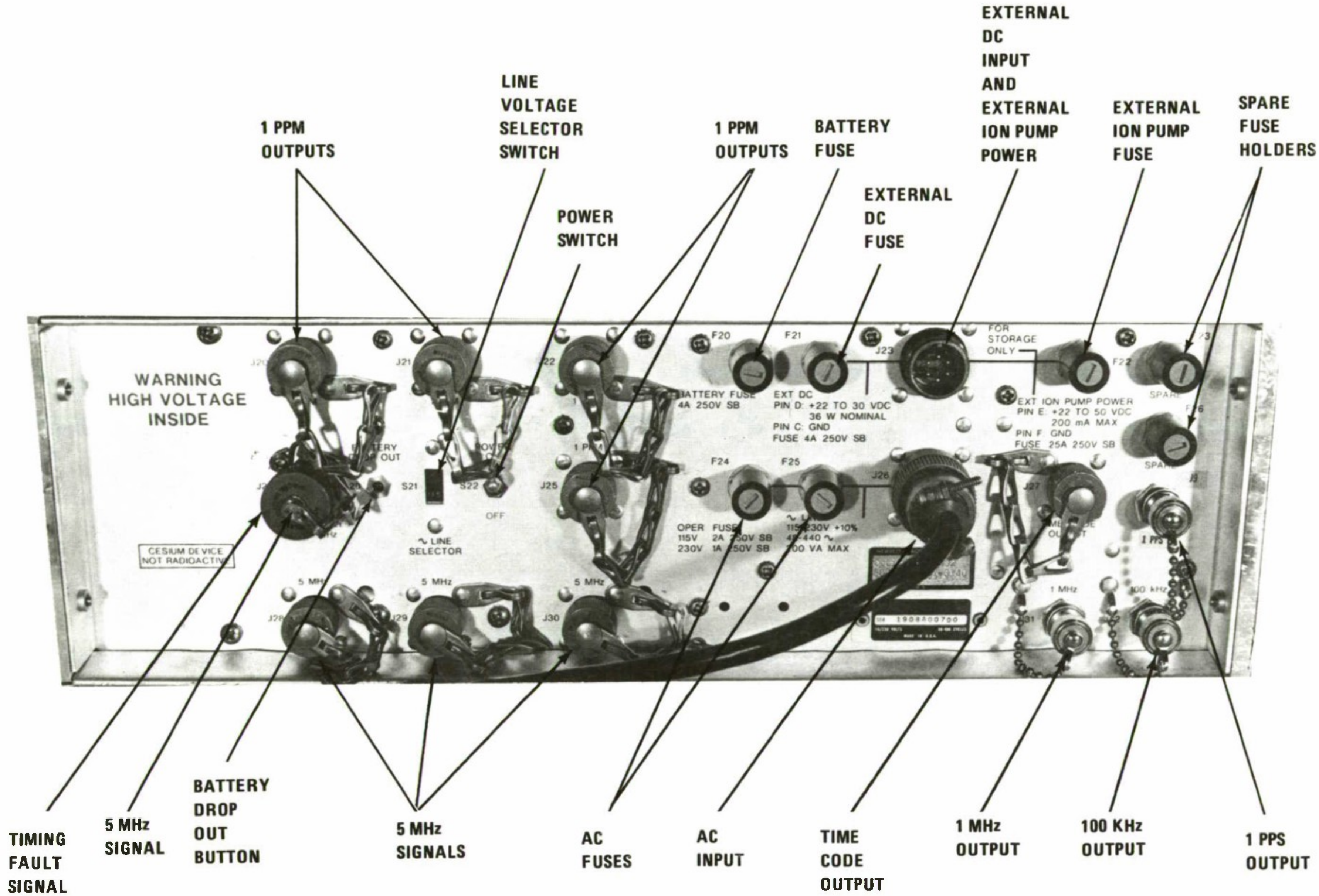


Figure 4-11 HP 5062C Rear Panel

i. AC FUSES

j. EXT DC FUSE

k. EXT DC connector - connect plus (+) side of power supply to pin D and negative (-) side to pin C. Pin C is connected to instrument chassis.

l. EXT ION PUMP POWER - for storage use only. Pin F is negative (-) or ground; pin E is positive (+).

m. AC LINE VOLTAGE connector - for ac power cord. Pin J is 115/230 V ac input; pin K is neutral, pin M is safety ground.

n. EXT ION PUMP FUSE

o. TIME CODE OUTPUT - a 24-bit, serial 8421 BCD code word occurring at a 50-bit-per-second rate. The code word is identical to the current time displayed on the instrument clock. Output is generated once every second and is synchronized with the 1 pps output. Pin A is the time-code signal; pin B is the signal return.

p. 1 MHz and 100 kHz outputs

q. 2 spare fuse holders

r. 1 pps on O-1695A/U

4.2.2 HP 5062C Unpacking and Inspection

Unpack the 5062C. Inspect all parts for damage (including scratches, dents, broken knobs, etc). If the 5062C is damaged in any way or fails any performance checks after installation, contact NAVELEX immediately for guidance.

4.2.3 HP 5062C Mechanical Mounting

The 5062C is shipped ready to use as a bench instrument. To convert it to rack-mounting, refer to the instructions in section 1, paragraph 1-35 of the Hewlett Packard Cesium Beam Frequency Reference 5062C Service Manual.

4.2.4 Connecting DC Power Supplies to HP 5062C

a. Ensure that dc power source is turned off.

b. Connect the positive (+) side of the external dc source to pin D of the 6-pin external dc mating connector on the back panel of the HP 5062C.

c. Connect the negative (-) side of the dc source to pin C of the mating connector. Pin C is connected to the 5062C chassis.

d. Connect the external dc connector to the 5062C and turn the dc power source on.

e. Set the 5062C rear-panel ON/OFF switch to ON (pull switch handle to unlock it).

f. The 5062C front-panel DC POWER lamp will be on. If ac power is also used, the AC POWER lamp will also be on. The 5062C will operate from the dc source only when ac operating power is not present or has been removed.

4.2.5 HP 5062C Turn-On Procedure

a. Ensure that the Line Voltage Selector on the back panel is set to the proper voltage (115 V or 230 V ac) BEFORE connecting power. Check the operating line voltage before changing the switch setting. Ensure that the correct fuse is installed (2 amp for 115 V ac and 1 amp for 230 V ac).

CAUTION

Never change the Line Voltage Selector switch setting with ac power connected. This will damage the instrument.

b. Connect ac power to the J26 connector on the back panel. Set POWER switch on back panel to ON (pull switch handle out to operate). The AC POWER lamp should be on.

c. Set MODE switch on front panel to LOOP OPEN. Set MODULATION switch to ON. (Pull switch handles out to operate.)

d. Compare the C-FIELD dial setting on the front panel to the setting shown on the front-panel door label. If these match, go to step e. If they do not match, contact NAVOBSY for guidance.

e. Wait a minimum of 20 minutes for instrument to warm up.

CAUTION

Set the CIRCUIT MONITOR METER to CS OVEN. The meter reading should be +50 during warm-up and should go down to +10 ±5 (at 25° C) afterward. If the reading is +50 for more than 15 minutes after turn-on (or for more than 15 minutes at any time), remove power immediately. Operation for a longer period at this level can damage the cesium beam tube.

f. Set MODE switch on front panel to OPER (pull switch handle out to operate).

g. Press LOGIC RESET button on front panel. The CONTINUOUS OPERATION light on the bottom of the front panel will come on and stay on. The ALARM light will be off.

h. The instrument is now operational. If the CONTINUOUS OPERATION light does not come on, or if the ALARM light is on, contact NAVOBSY for guidance.

i. Set the CIRCUIT MONITOR meter to each of the 12 positions and compare the meter readings observed with the values shown in the table on the front-door label. Record the readings in the instrument log book. During the first few days of operation, some of the meter readings may change as signal levels stabilize. This is normal and does not affect the frequency accuracy of the instrument. During this period, the BEAM I and CONTROL readings should be checked daily. See 4.2.13 for acceptable meter readings.

j. If the BEAM I indication is below +15 or above +35, set the meter switch to BEAM I and turn the BEAM I ADJ control for an indication of +30.

k. If the CONTROL indication is below -25 or above +25, set the meter switch to CONTROL and turn the OSC FREQ control with a screwdriver for a zero indication. If the CONTINUOUS OPERATION light goes out, press the LOGIC RESET button.

l. Record the following dial readings and switch settings into the log book:

1. C-FIELD
2. MODULATION
3. MODE

4.2.6 HP 5062C Warning Lights

If the ALARM lamp lights while the CONTINUOUS OPERATION light remains on, set the CIRCUIT MONITOR switch to CONTROL and turn OSC FREQ for a zero indication. If the CONTINUOUS OPERATION light goes out, press LOGIC RESET.

If the CONTINUOUS OPERATION light goes off during normal operation, the unit may be off frequency. Contact NAVOBSY for guidance.

4.2.7 HP 5062C Clock Synchronization

If an electrically compatible sync pulse is available from a reference source, it may be used to automatically synchronize the 5062C 1 pps output to the reference source. If no compatible sync pulse is available, the 5062C may be manually synchronized.

4.2.7.1 Automatic Synchronization

The external sync pulse must be +4 V to +10 V into 50 ohms, 0.5 μsec minimum width, and less than 50 nsec rise-time. The 1 pps output from the HP 5061A, and the 1 pps and 1 ppm outputs from the 5062C fulfill these requirements. The 5062C will automatically synchronize to within ±500 nsec of the positive-going edge of the reference pulse. To automatically synchronize the clock, perform the following procedure.

a. With the 5062C operating normally, connect the external reference sync-pulse to the 5062C front-panel SYNC connector.

b. Set the TIME ADVANCE switches to 000000.0.

c. Press and hold the front panel SYNC switch for at least 1 second.

d. Release the SYNC switch. The 5062C 1 pps and 1 ppm outputs are now synchronized to the reference pulse. The clock seconds display will be 00, and the unit-of-minutes will increment one digit coincident with the sync signal.

e. Synchronization can be verified by using an oscilloscope or time interval counter to compare the 5062C 1 pps and the reference sync pulse.

4.2.7.2 Manual Synchronization

The 5062C 1 pps and 1 ppm outputs can be advanced, using the TIME ADVANCE switch, to coincide to within ±50 nsec with a pulse from a reference source. The 5062C 1 pps signal can be compared and advanced, using either an oscilloscope or a time interval counter, by performing the following procedure.

a. Connect the 5062C as shown in figure 4-12. When using the time interval counter, terminate the 5062C 1 pps output cable with a 50-ohm load to minimize pulse ringing.

b. When using a time interval counter, set the 5062C TIME ADVANCE μSEC to 000000.0. When using an oscilloscope, go to step f.

c. Set the counter time base controls for a resolution of 0.1 μsec.

d. Set the time interval unit to trigger on the leading edges of the two input pulses. The leading edge of the 5062C output is the positive-going edge.

e. Set the 5062C TIME ADVANCE switches for the desired offset as displayed on the counter. The time-of-day may now be set.

f. When using an oscilloscope, set the oscilloscope controls to display both pulses. Ensure that the oscilloscope is set to EXTERNAL SYNC.

g. Adjust the 5062C TIME ADVANCE thumbwheel switches for coincidence, or for the desired offset between the 5062C 1 pps pulse and the reference source clock pulse.

4.2.8 HP 5062C Time-of-Day Setting

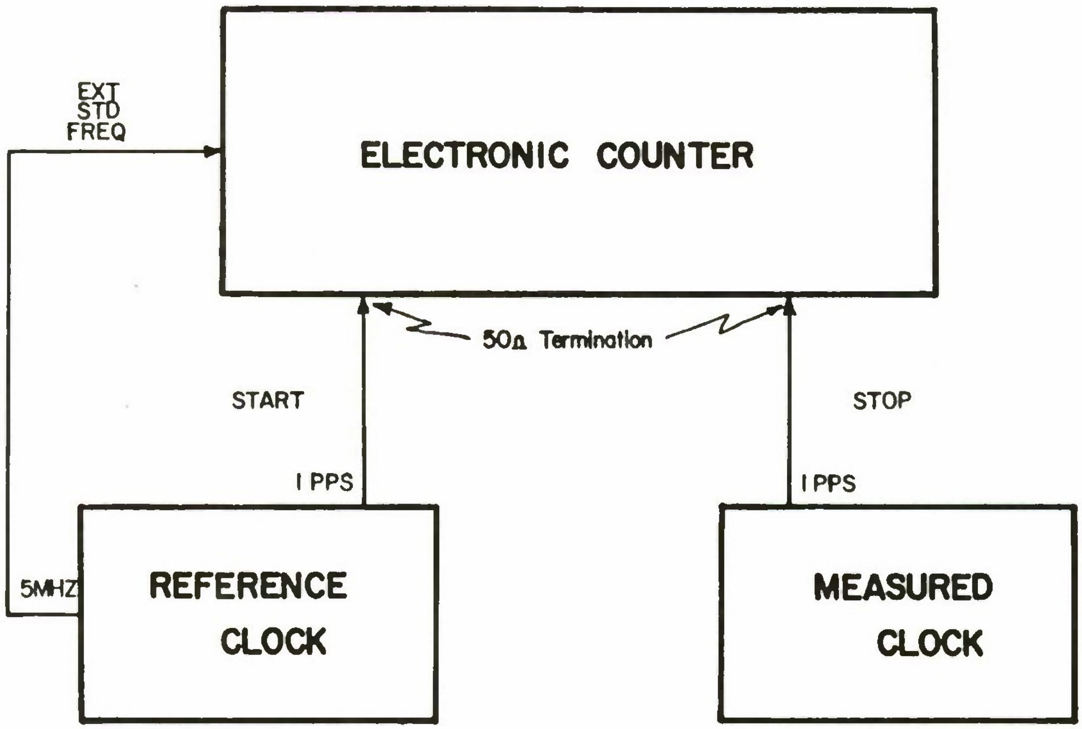
The 5062C clock display can be set to any desired time, advanced or delayed, or one count can be added or subtracted on the display. To set the display, perform the following procedure.

a. To delay the display when it is ahead of the reference time, set and hold the SET/HOLD switch into the SET/HOLD position until the reference clock catches up with the 5062C display. Release the switch.

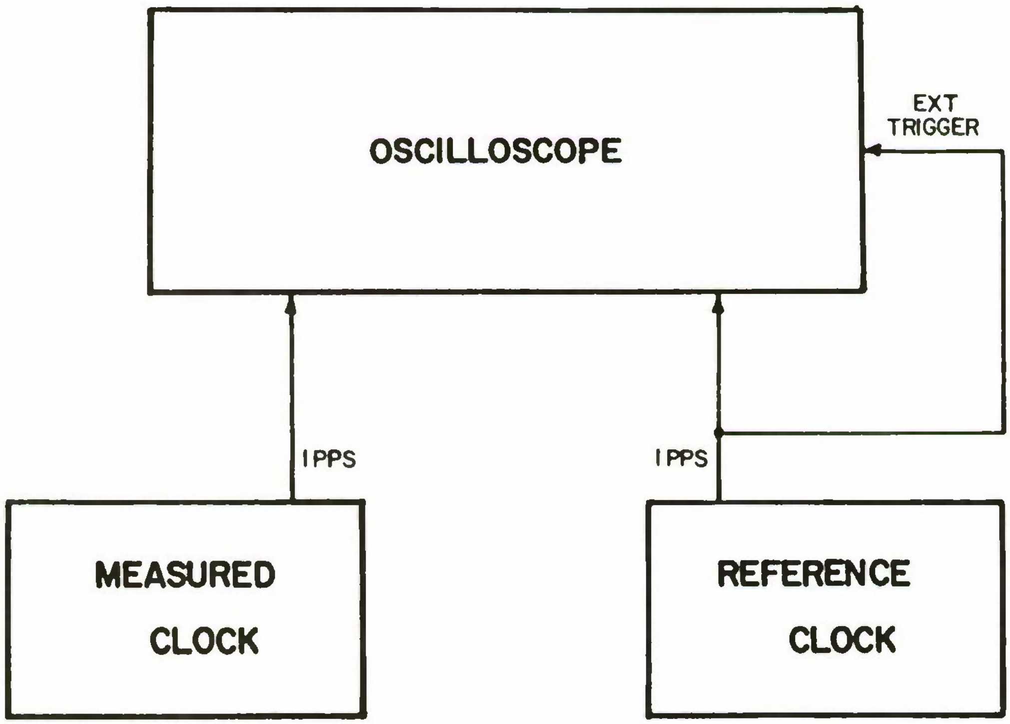
b. To advance the display when it is behind the reference time, set and hold the SET/HOLD switch into the SET/HOLD position. At the same time, press and hold the HOURS, MINUTES, or SECONDS switches to set the corresponding portion of the display time slightly ahead of the reference clock. Continue holding the SET/HOLD switch until the reference clock catches up with the 5062C display. Release the switch.

NOTE

The SET/HOLD switch is self-locking. Pull the switch handle to unlock it.



A. Time Interval Counter



B. Oscilloscope

Figure 4-12 1 PPS Manual Synchronization

If further adjustments are needed, add or subtract one count (hours, minutes, or seconds) by the following procedure.

a. Press and hold either the HOURS, the MINUTES, or the SECONDS button. At the same time, press and hold the CLOCK SUB/ADD in either the ADD or the SUB position until the display adds or subtracts one count.

b. When the display changes, release the CLOCK SUB/ADD switch for one second, then repeat the procedure if additional changes are desired. The display will add or subtract only one count each time the CLOCK SUB/ADD switch is pressed.

c. Adding and subtracting one count to the SECONDS portion of the display can be awkward since the display changes at a 1-second rate. It may be easier to advance or delay the seconds display by using the SET/HOLD switch as described above.

4.2.9 HP 5062C 1 PPM Reset

The regular clock synchronization procedure synchronizes the 1 pps and 1 ppm outputs to occur on the 60th second on the clock display. The 1 PPM RESET is used to synchronize the 1 ppm output with a 1 pps output pulse that occurs from 0 to 59 seconds. To accomplish this, perform the following procedure.

a. Determine at which second (0 to 59) of the display you want to synchronize the 1 ppm output pulse and wait until the number immediately preceding the one you want appears on the seconds portion of the display.

b. Press the recessed 1 PPM RESET button. A pencil, pen, or similar pointed tool may be used to reach this button.

c. The 1 ppm output will be synchronized with the next occurring 1 pps pulse. The seconds portion of the clock display will reset to zero (00) and the minutes portion of the display will advance one digit.

CAUTION

Using the 1 PPM RESET will change the time-of-day on the clock display.

d. The 1 PPM RESET button must be released before the cycle can be repeated.

4.2.10 HP 5062C UTC Step Adjustment

To conform to Coordinated Universal Time (UTC), a one-second adjustment to the 5062C is occasionally required. To make this adjustment, perform the following procedure.

a. Momentarily (less than one-half second) press the recessed UTC STEP button. A pencil, pen, or similar pointed tool may be used to reach this button.

b. One pulse will be subtracted from both the 1 pps and the 1 ppm outputs. The clock display will be retarded by one second.

CAUTION

Do NOT hold the UTC STEP button or press it for as long as 0.5 seconds or longer. This would delay the outputs and display by more than one second.

NOTE

This adjustment should only be made after receiving an announcement from NAVOBSY stating that UTC will be adjusted by one second.

4.2.11 HP 5062C Internal Standby Battery

The HP 5062C is equipped with internal, standby battery power. The battery is rated to provide a minimum of 1 hour of operation at 25° C, or to provide 30 minutes at 55° C and 20 minutes at -28° C when the battery has been fully charged at 25° C.

The BATTERY POWER lamp on the 5062C will be lit when battery power, in any amount, is available for use. It does not indicate how much power is available or if the battery is currently in use.

Battery recharge is automatic when external power is available. The recharge time is variable depending on the ambient temperature and the original charge-state of the battery. Full recharge will take approximately 48 hours, but 1 hour of standby power should be available in 8 to 16 hours.

The 5062C is equipped with two charging rates, fast charge and float charge. Both are automatic. The battery will use the fast charge cycle for a complete charge and the float charge cycle to maintain power afterward. The FAST CHARGE lamp will light whenever that cycle is in operation. It will vary in intensity, with the maximum brightness indicating a maximum charge rate. The FAST CHARGE lamp may also light momentarily, even if the battery is fully charged, when external power is connected.

The INT BATT I meter reading on the CIRCUIT MONITOR will also vary in the 5062C with the rate of charge. The reading will be about +22 during fast charge, -40 during discharge, and will increase to a float charge level of 0.

When the instrument is operating on internal battery power, the digital clock display will be off. To read the display, press STANDBY DISPLAY. Extensive use of the STANDBY DISPLAY button will significantly decrease the available power.

4.2.11.1 Internal Standby Battery Problems

It has been found that internal standby battery power often lasts for significantly and unpredictably shorter periods than expected. The battery lights and meter readings cannot be relied on as true indicators of the available power capacity. The operator should be aware that there may be less time available on standby power than the indicators may show. The time available can vary from as much as the full rated time to as little as less than a minute. The indicators will only tell the operator when there is zero time available.

When external power is disconnected from the instrument, it will automatically switch to internal battery power. If there is insufficient power, or if the battery system is defective, the instrument will simply stop operating.

When external power is reapplied, the instrument may make a chattering noise. This is the low voltage sensoring relay. If the chattering stops within 15 minutes, the battery will recharge normally. If the chattering continues for more than 15 minutes, it is an indication that the battery pack is defective and must be replaced. Remove the battery and continue instrument operation on external power. Contact NAVELEX Engineering Center, PTT Office, USNO. Phone: commercial - (202) 254-4021; AUTOVON - 294-4021.

4.2.11.2 HP 5062C Internal Standby Battery Removal and Replacement

a. Turn off all operating power before removing battery.

b. Remove top instrument cover by unscrewing, lifting about 1 cm, and sliding directly back.

c. Disconnect the black terminal (-), then the red terminal (+) wires from the battery.

d. Remove the battery pack cover by removing 11 screws.

e. Remove the batteries one at a time. Install new batteries one at a time. New batteries should be positioned with the negative terminals (-) toward the instrument rear panel.

f. Reinstall the battery pack cover. Be careful not to short the battery terminals with the cover.

g. Reinstall the battery wires; black terminals to the battery negative terminals (-) and red terminals to the battery positive terminals (+).

h. Reapply operating power.

NOTE

If the batteries are more than 6 months old, all four battery packs should be changed if a failure occurs in one pack.

4.2.12 Cesium Frequency Standard C-Field Control

The C-Field Control reading consists of three digits, as shown in figure 4-13.

a. The first digit is the last number on the dial passed by the small hand.

b. The second digit is the last number on the dial passed by the large hand.

c. There are ten units between every two numbers on the dial. Every other unit is marked. The third digit is the number of units between the large hand and the last number that it passed.

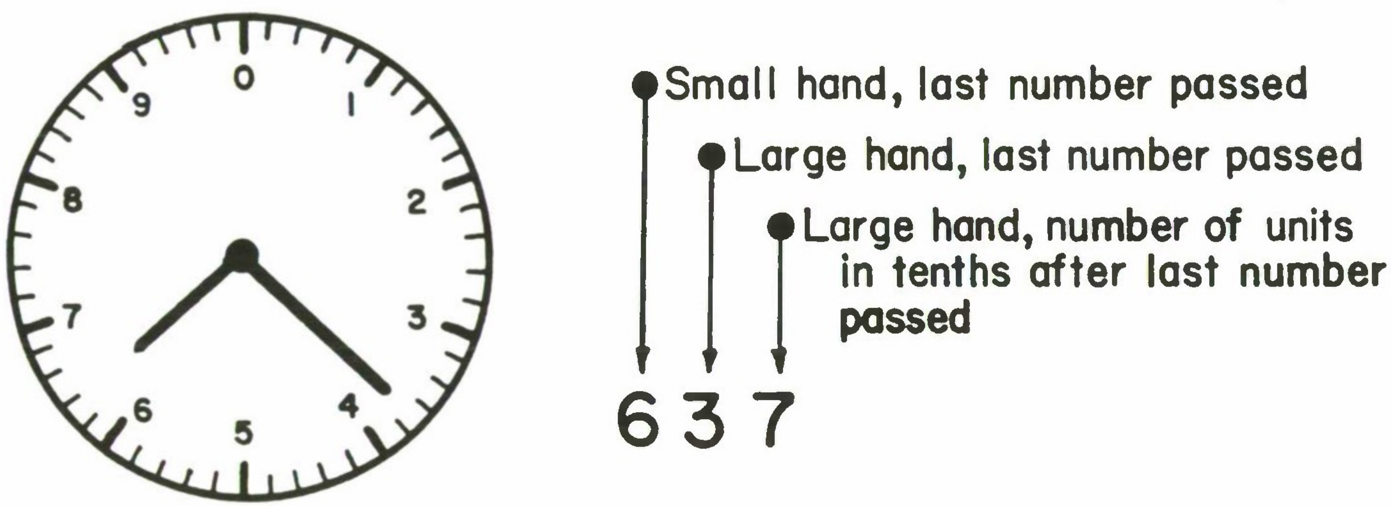


Figure 4-13 C-Field Control Reading

4.2.13 HP 5062C Weekly Checks

Once each week, set the CIRCUIT MONITOR switch to each of the 12 positions and record the meter readings into the instrument log book. The following meter readings are acceptable for field operations:

Position	Initial Reading (During Warm-Up)	Normal Reading (After Warm-Up)
0 SUPPLY	+30	+30 ±5
1 +18V	+30	+30 ±5
2 +5V	+30	+30 ±5
3 INT BATT I	-1 to +25 (at 25° C) during charge	-35 to -50 during discharge
4 ION PUMP	-1 to +40	+10
5 5 MHz	+30	+30 ±5
6 OSC OVEN	+50	+10 ±5 (at 25° C)
7 CS OVEN	+50	+10 ±5 (at 25° C)
8 SYNTH	+30	+30 ±5
9 BEAM I	0	+15 to +35 (operator adjustable)
10 2ND HARM	0	+15 to +35
11 CONTROL	0 (MODE switch in LOOP OPEN)	-25 to +25 (operator adjustable)

In addition to the meter readings, record the following dial readings and switch settings:

C-FIELD	-
MODULATION	ON
MODE	OPER

There are two conditions that require operator adjustment after the monthly readings are recorded:

a. The BEAM I reading is above +35 or below +15.

b. The CONTROL reading is above +25 or below -25. The ALARM lamp will turn on.

When one of the above occurs, the operator will make the appropriate adjustment below.

a. Set the CIRCUIT MONITOR switch to the BEAM I position and turn BEAM I ADJ until the meter reads +30. If BEAM I ADJ lacks sufficient adjustment range, the 5062C will perform correctly until the meter indication drops to approximately +10, at which time the CONTINUOUS OPERATION light will go out and the instrument should be removed for servicing.

b. Set the CIRCUIT MONITOR switch to CONTROL and slowly turn the OSC FREQ control with a screwdriver until the meter reads 0.

NOTE

Turning the OSC FREQ clockwise moves the meter to the left, counterclockwise moves it to the right. During adjustment, the CONTINUOUS OPERATION light may go off; this is normal. When the adjustment is completed, press the LOGIC RESET button to relight the CONTINUOUS OPERATION lamp.

Enter a brief summary of any adjustments made and the new meter readings in the instrument log book.

4.2.14 Cesium Frequency Standard Turn-Off Procedures

The Cesium Beam Frequency Standards that have internal batteries will continue to operate on internal battery power when external ac and dc power are removed. The following procedure should be performed to turn units off.

a. Remove external ac and dc power.

b. Press the recessed rear-panel BATTERY DROP OUT switch. This disconnects the internal battery supply and stops all clock operation. The unit will start operating and the battery will be automatically reconnected when external power is applied.

CHAPTER 5

STANDBY POWER SUPPLIES

WARNING

The electrolyte in the 5085A battery is caustic, poisonous, and dangerous to eyes, skin, and clothing. If electrolyte sprays or spills on body or clothing, remove clothing from the affected area immediately to prevent further contact with the solution. Wash the area thoroughly with cold water until the soapy feeling is gone and skin feels clean. Do NOT apply other chemicals or ointments to burn area. Wrap area tightly with sterile dressing to prevent blistering; excluding air reduces pain of burn.

If electrolyte gets into an eye, wash the eye immediately and completely in cold water. If possible, hold the head so water runs from inner to outer corners of the eye. Roll the eye while washing to ensure complete irrigation.

SEEK IMMEDIATE MEDICAL ATTENTION after first aid.

WARNING

Do NOT turn batteries upside down. Do NOT tilt instrument more than seep through vent plugs.

WARNING

Be careful when working around battery. A short circuit may cause current greater than 100 amperes.

WARNING

When removing fill caps, cover the cell battery with a cloth to prevent eye injury from accidental electrolyte spills.

CAUTION

Do NOT use items or tools that have previously been used with acid batteries. Only pure distilled or demineralized water should be added to the 5085A batteries (do not use water labeled "water for batteries" which may contain sulfuric acid). Keep all acid away from the 5085 alkali batteries. Acid ruins an alkali battery.

CAUTION

Never overfill a battery cell.

5.1 HP 5085A AND AUSTRON 1290-A STANDBY POWER SUPPLIES

The HP Cesium Beam Frequency Standards use HP 5085A or Austron 1290-A Standby Power Supplies to ensure uninterrupted power. Both the 5085A and the 1290-A provide regulated 24 V dc. The 5085A has a 21 ampere-hour and the 1290-A has a 20 ampere-hour standby capability when fully charged. With the internal batteries at a normal charge level (60 percent) at 25° C, the 5085A has a standby capability of 14 ampere-hours. The 1290-A has a capability of 18 ampere-hours. Both consist of:

a. 115/230 V ac to 32 V dc supply
b. Output voltage regulator
c. Battery charge regulator
d. Rechargeable internal storage battery
e. Relay and indicator circuits.

When operating from ac line voltage, the supply provides regulated 24 V dc to the load and charging current to the standby battery in both the 5085A and the 1290-A. When ac power is interrupted, the battery immediately supplies power to the load and the relay switches. The AC INTERRUPT light indicates the interruption of line power. When ac power resumes, it immediately resumes powering the load and charging the battery. The INTERRUPT light remains on until the RESET button is pressed.

5.1.1 Standby Power Supplies Physical Characteristics

5.1.1.1 Front Panel

	5085A (Figure 5-1)	1290-A (Figure 5-3)
a.	AC POWER lamp	AC POWER lamp
b.	AC INTERRUPT lamp	AC INTERRUPT lamp
c.	AC RESET button	AC RESET button
d.	2 FUSE FAILURE lamps	2 FUSE FAILURE lamps

	5085A (Figure 5-1)	1290-A (Figure 5-3)
e.	RESERVE CHARGE lamp and switch	BATTERY CHARGE lamp and switch
f.	BATTERY VOLTAGE meter	BATTERY VOLTAGE meter
g.	BATTERY CURRENT meter	BATTERY CURRENT meter

5.1.1.2 Rear Panel

	5085A (Figure 5-2)	1290-A (Figure 5-4)
a.	115/230 VOLT switch	S1 115/230 V switch
b.	AC LINE jack for female connector	J1 AC line jack for female connector
c.	2 AC LINE FUSES	F1 and F2 ac line fuses
d.	OSCILLATOR OUTPUT jack	J5 OSCILL OUT jack
e.	CLOCK OUTPUT jack	J4 CLOCK OUT jack
f.	EXTERNAL BATTERY CURRENT potentiometer	none
g.	EXTERNAL BATTERY jack	J3 external battery jack
h.	EXT ALARM jack	J2 external alarm jack
i.	none	J6 thru J9 extra jacks

5.1.2 Unpacking and Inspection

Unpack the instrument and inspect for visible physical damage. If any damage is found or if the instrument does not meet specifications, contact NAVOBSY immediately for guidance.

The batteries are shipped separately. The 1290-A uses sealed batteries that require no maintenance. For the 5085A, check to see if any liquid has spilled into the shipping container. This may be a sign of a damaged battery cell. Check to be sure there is liquid in every cell (tip battery, if necessary). If no liquid is present, add no more than 10 cc of distilled water to the cell. Check vent plugs to be sure they are not obstructed. Test screws and nuts on all terminals of all batteries (including the 1290-A). Poor electrical contact may damage the battery.

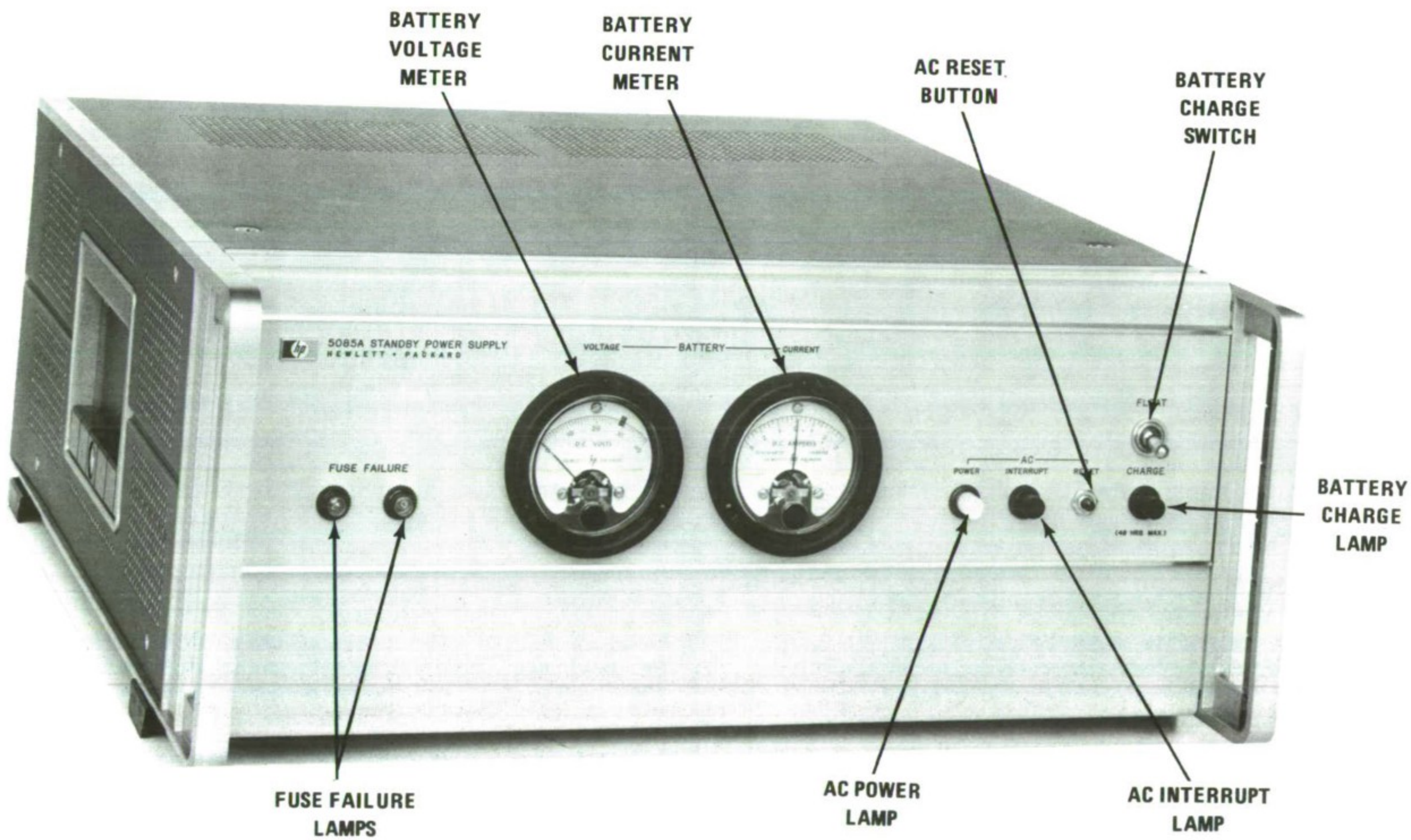


Figure 5-1 HP 5085A Front Panel

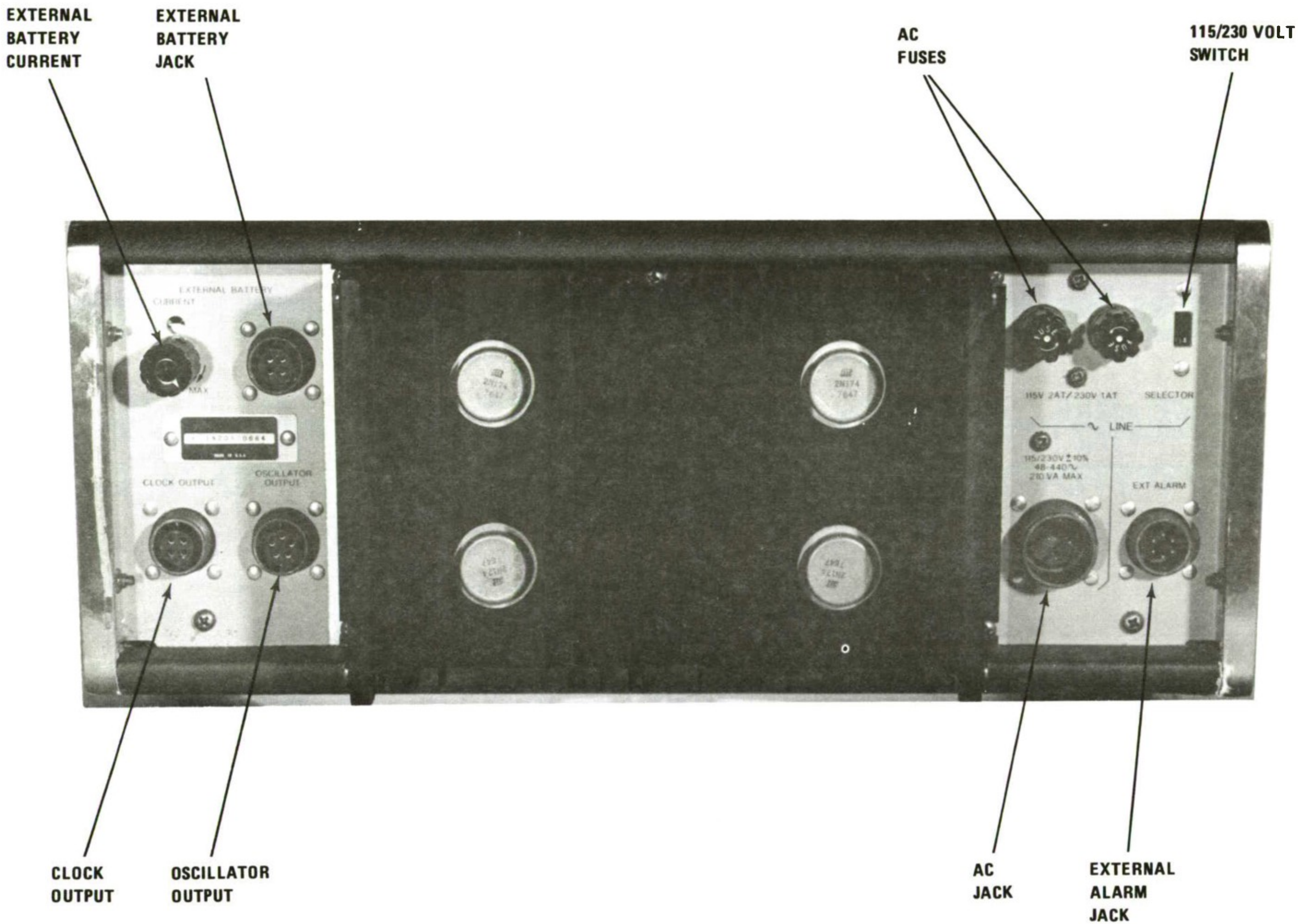


Figure 5-2 HP 5085A Rear Panel

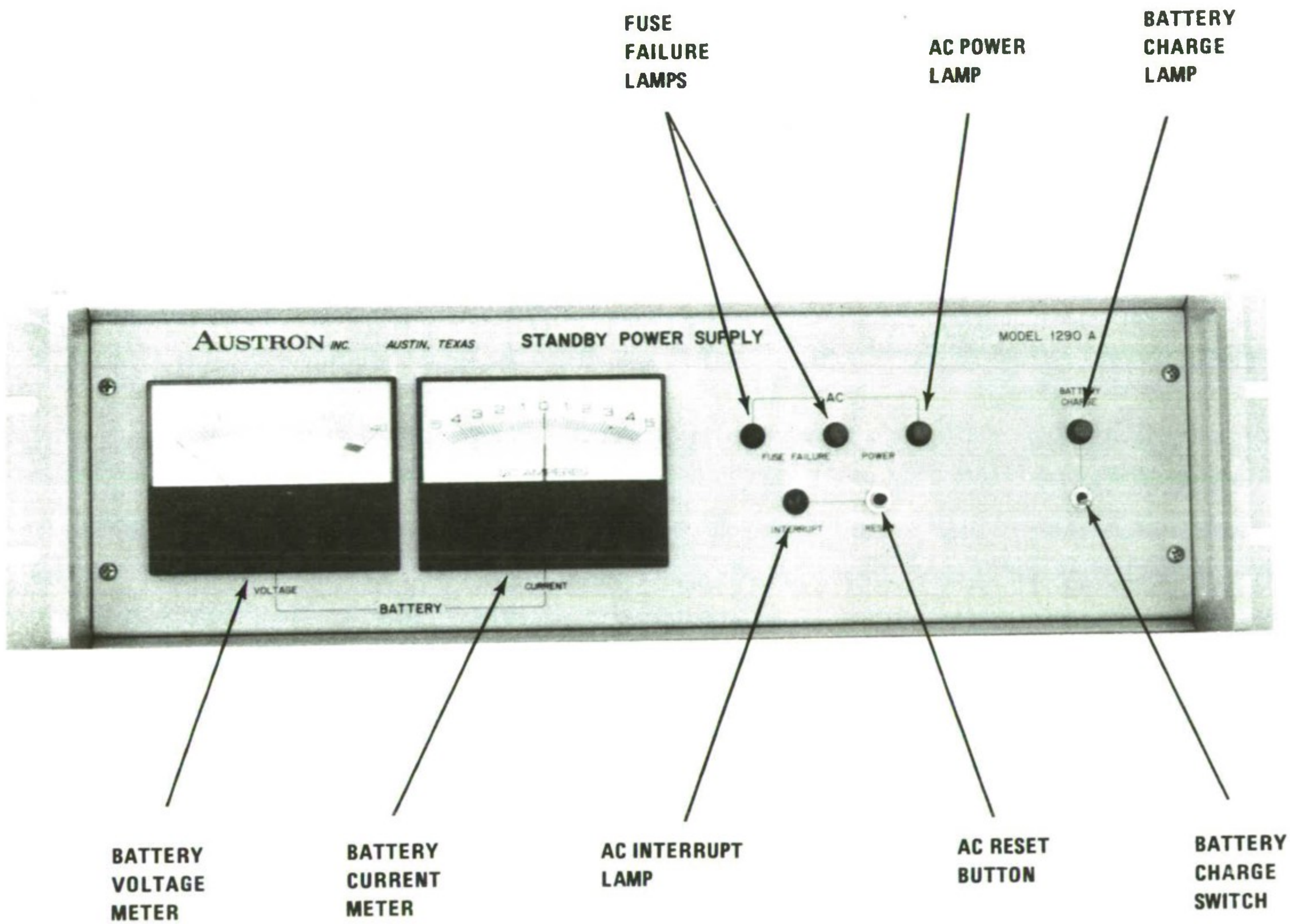


Figure 5-3 Austron 1290-A Front Panel

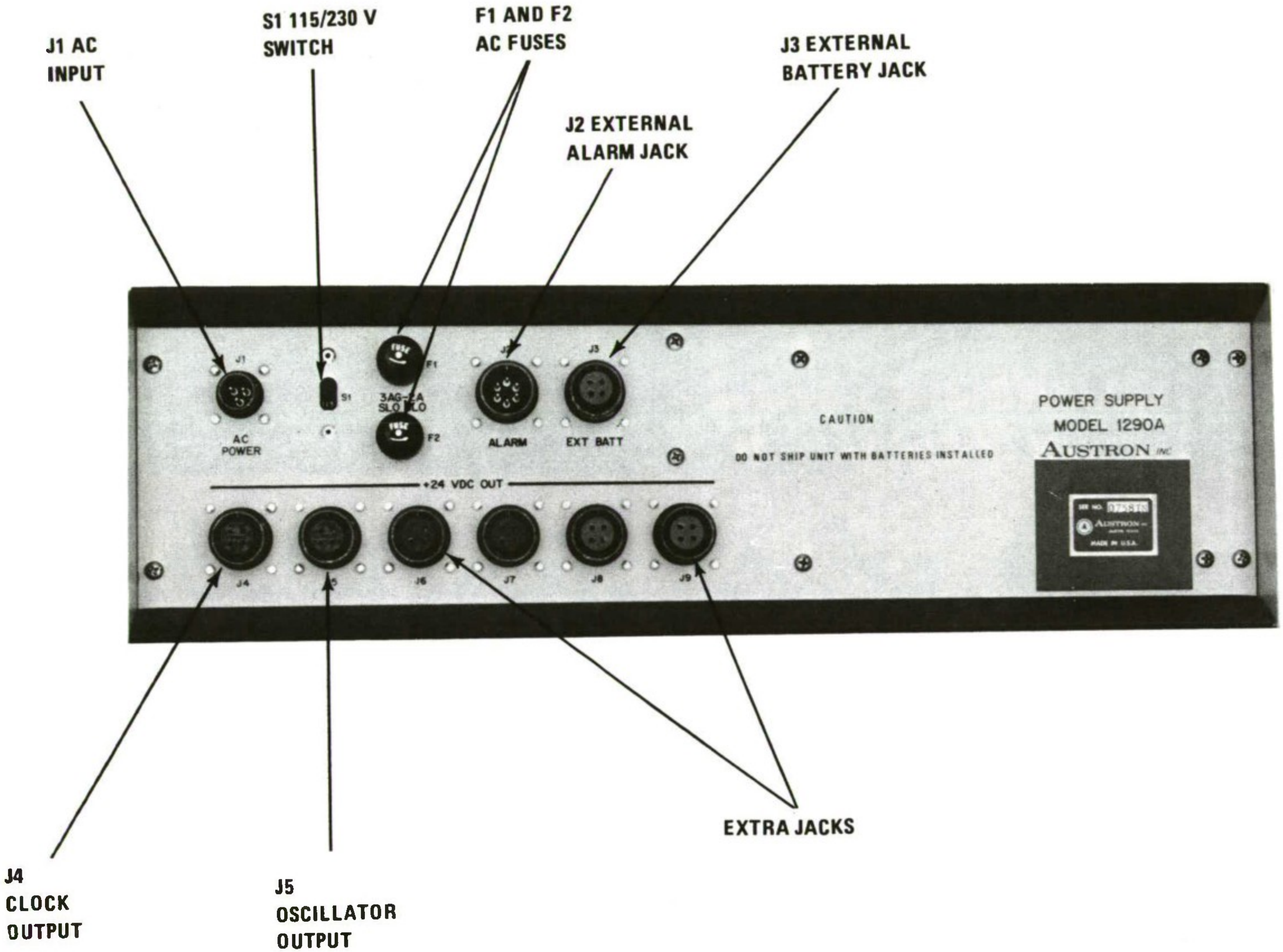


Figure 5-4 Austron 1290-A Rear Panel

5.1.3 Battery Installation

This is a general procedure. See Instruction Manual for details.

a. Remove top cover of instrument.

b. Install batteries.

c. Tighten all battery brackets and screws.

d. Install two battery shields in 5085A. Horizontal sections without holes are "up," pointing away from each other. Battery must be disconnected. Tighten remaining screws.

e. Connect appropriate wire to positive terminal (+) of left battery.

f. Connect appropriate wire to negative (-) terminal of right battery.

g. Connect short jumper between batteries. The spark that occurs is normal.

h. Replace covers.

i. Check battery condition on front panel meters.

j. To remove battery, reverse procedure. Lift battery out by running strong twine or other nonconductor under the battery and lifting.

5.1.4 Instrument Installation

Both the 5085A and the 1290-A are designed to be rack mounted. They require a free air flow around the rear and sides of the instrument to cool the components and, in the 5085A, to remove oxygen and hydrogen produced during battery charging. Keep the instruments away from heat producing equipment.

5.1.5 Standby Power Supplies Operation

To turn the standby power supply on, perform the following procedure:

a. Set the 115/230 volt switch on the rear panel to the appropriate line voltage.

b. Plug the instrument into the ac power source. The AC POWER light will come on and the instrument will be operational. There is no on/off switch. No warm-up time is necessary.

c. Check to be sure that the following indicators register properly.

1. AC POWER lamp - on
2. AC INTERRUPT lamp - off

3. FUSE FAILURE lamps - off

4. RESERVE CHARGE (5085A) or BATTERY CHARGE (1290-A) lamp - off, unless the RESERVE CHARGE (5085A) or BATTERY CHARGE (1290-A) switch is set to charge.

5. BATTERY VOLTAGE meter - 28 to 30 V (5085A) or 27 V (1290-A)

6. BATTERY CURRENT meter - 0.05 to 0.75 amp (5085A) or 0.01 to 0.03 amp (1290-A). The current will drop to the minimum when the batteries are fully charged.

5.1.6 Battery Charging

During normal operation, at 60 to 70 percent capacity, the 5085A will have sufficient power to operate a Cesium Beam Frequency Standard for approximately nine hours at 25° C. The 1290-A will have sufficient power for approximately eleven hours of operation. If standby power may be needed for a longer period, the batteries can be fully charged to provide fourteen hours of power by the 5085A or twelve and a half hours by the 1290-A.

To fully charge the standby batteries, set the RESERVE CHARGE switch on the 5085A or the BATTERY CHARGE switch on the 1290-A to charge. When the battery is fully charged, return the switch to the normal setting. The batteries will be float-charged to maintain the highest charge level attained as long as ac power is available.

5.1.7 Standby Power Supplies Maintenance

The meters and indicator lights on both the 5085A and the 1290-A should be checked periodically to ensure normal readings.

The Austron 1290-A uses sealed batteries that require no maintenance. If a battery is defective, see f below. The HP 5085A batteries require periodic maintenance as follows.

a. At installation and periodically thereafter, ensure that the electrolyte is at the correct level in every cell. When the battery is fully charged, the electrolyte should be 1/16 to 1/8 inch above the tops of the plates in each cell. Do <u>not</u> allow the level to fall below the bottom of the window on the inside of the battery.

b. If electrolyte is needed, add only distilled or demineralized water.

c. During normal operation, the electrolyte levels should be checked every two weeks. When the battery is in the RESERVE CHARGE mode, however, the levels should be checked every three days. Also, if there are frequent charge/discharge cycles, the levels should be checked every week.

d. Harmless potassium carbonate (a white powdery substance) will accumulate on the battery terminals and vent plugs. This powder should be carefully removed before removing the vent plugs. Every four weeks, inspect and remove any powder deposits from the terminals, panel, etc with a clean, dry, nonmetallic brush. Wipe the instrument dry with a clean, soft, dry cloth. Inspections and cleaning should be more frequent in areas of high temperature or humidity or if frequent charge/discharge cycles occur.

e. At least once a year, remove the complete vent plug assemblies. Wash them in warm water, dry them thoroughly, and replace them on the battery.

f. If a cell or battery will not charge to the proper voltage or is otherwise defective, it should be removed and discarded. For information, see the effective Logistics Bulletin or contact NAVOBSY.

If a NAVOBSY HP 5085A or Austron 1290-A is defective beyond station repair capability for any reason other than batteries, report it as defective, listing all abnormal indications, to NAVOBSY, Washington, D.C., for disposition instructions. Send an information copy of the report to NAVELEXSYSENGCEN, Portsmouth PTTI Office.

5.2 HP MODELS K02-5060A AND K24-5060A

The K02-5060A Standby Power Supply is used to supply power to portable cesium standards. It provides both 230 V ac primary power and +26 V dc (nominal) standby power. The 230 V ac output voltage and battery charge current are adjustable. The +26 V dc is obtained from four rechargeable internal battery packs that provide 6 to 7 hours of standby power. Primary power to the K02-5060A can be 115 V ac, 230 V ac, +6 V dc, or +12 V dc. A special inverter circuit allows the K02-5060A to be used with dc primary power sources also.

The K24-5060A is a modification of the K02-5060A in which any one of the four individual battery packs can be exercised independently by operating one of four toggle switches that are added to the rear panel. The instrument must be operating from an ac power source while this feature is in use.

5.2.1 Physical Characteristics

5.2.1.1 Front Panel (Figure 5-5)

a. AC voltage control (VARIAC)
b. CHARGING CIRCUIT, AC, and DC fuses
c. 24 V dc dual connector for temporary 24 to 30 V dc auxiliary input
d. DC CHECK switch
e. Output meters for voltage and current. If the ammeter reads over 1 ampere, the batteries are being discharged; if less than 1 ampere, the batteries are being charged with each battery receiving 25 percent of the charge. The difference between 1 ampere and the ammeter indication is the total charging current.
f. AC ON lamp
g. POWER switch
h. CONVERTER START 6V dc button for manual start when necessary

5.2.1.2 Inside Top Cover (Figure 5-6)

a. 4 BATTERY DISCONNECT SWITCHES

5.2.1.3 Rear Panel (Figure 5-7)

a. AC IN jack
b. AC OUT jack
c. DC IN jack
d. DC OUT jack
e. VARIAC 3A fuse
f. BT1, BT2, BT3, and BT4 toggle switches (on K24-5060A only)
g. Binding post connectors for voltage monitoring devices (on K24-5060A only)

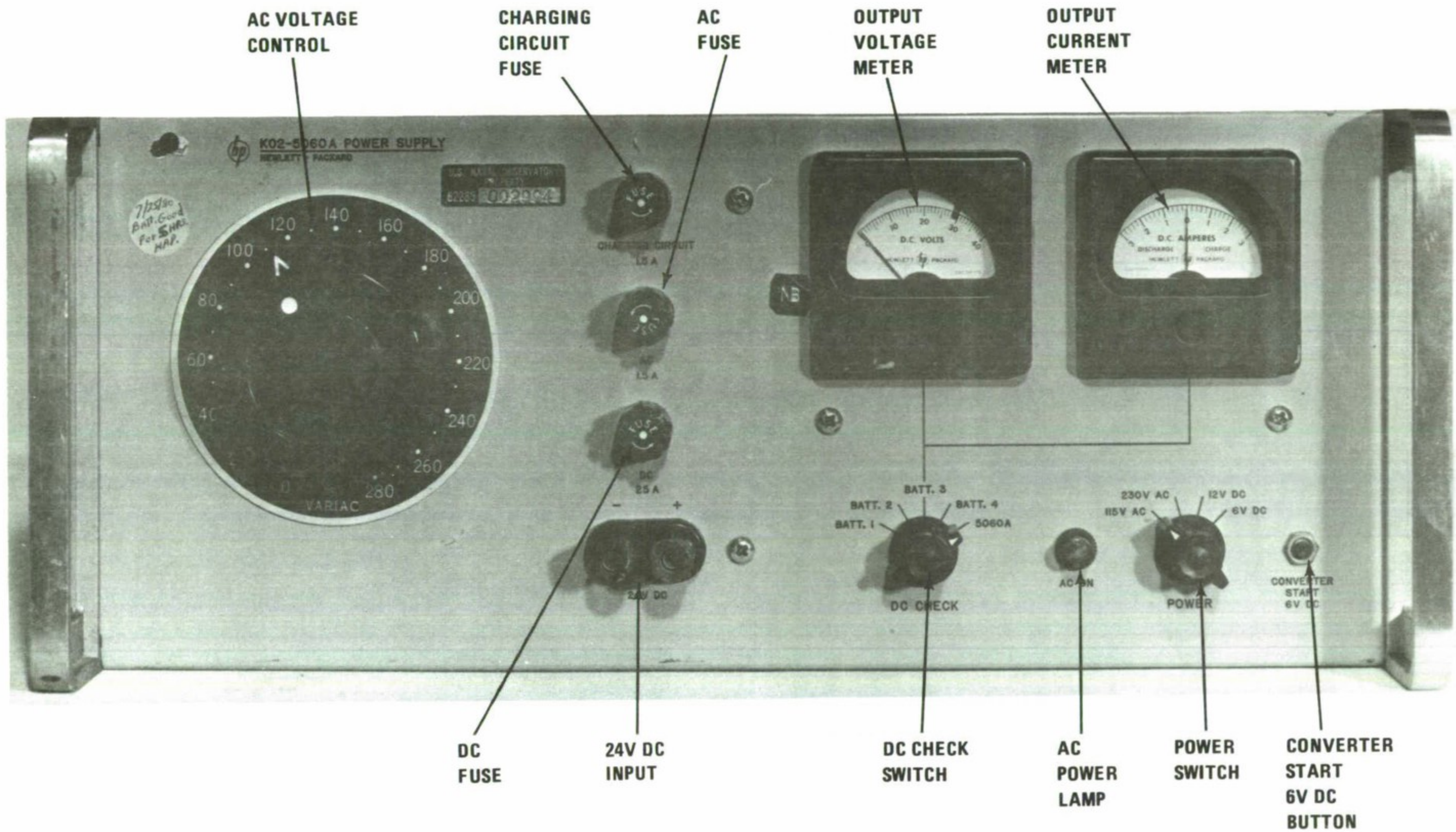


Figure 5-5 K02-5060A Front Panel

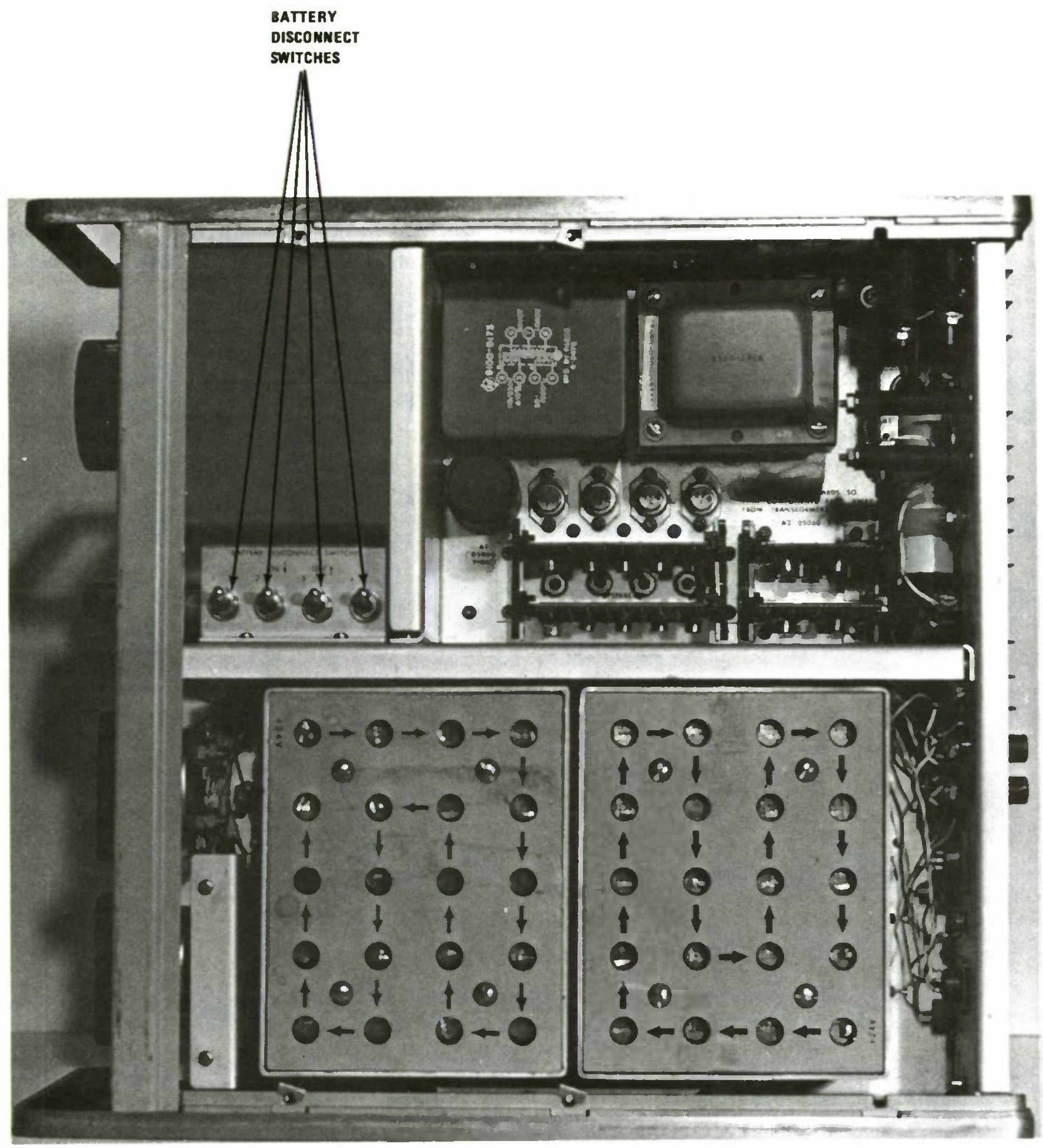


Figure 5-6 K02-5060A Inside Top Cover

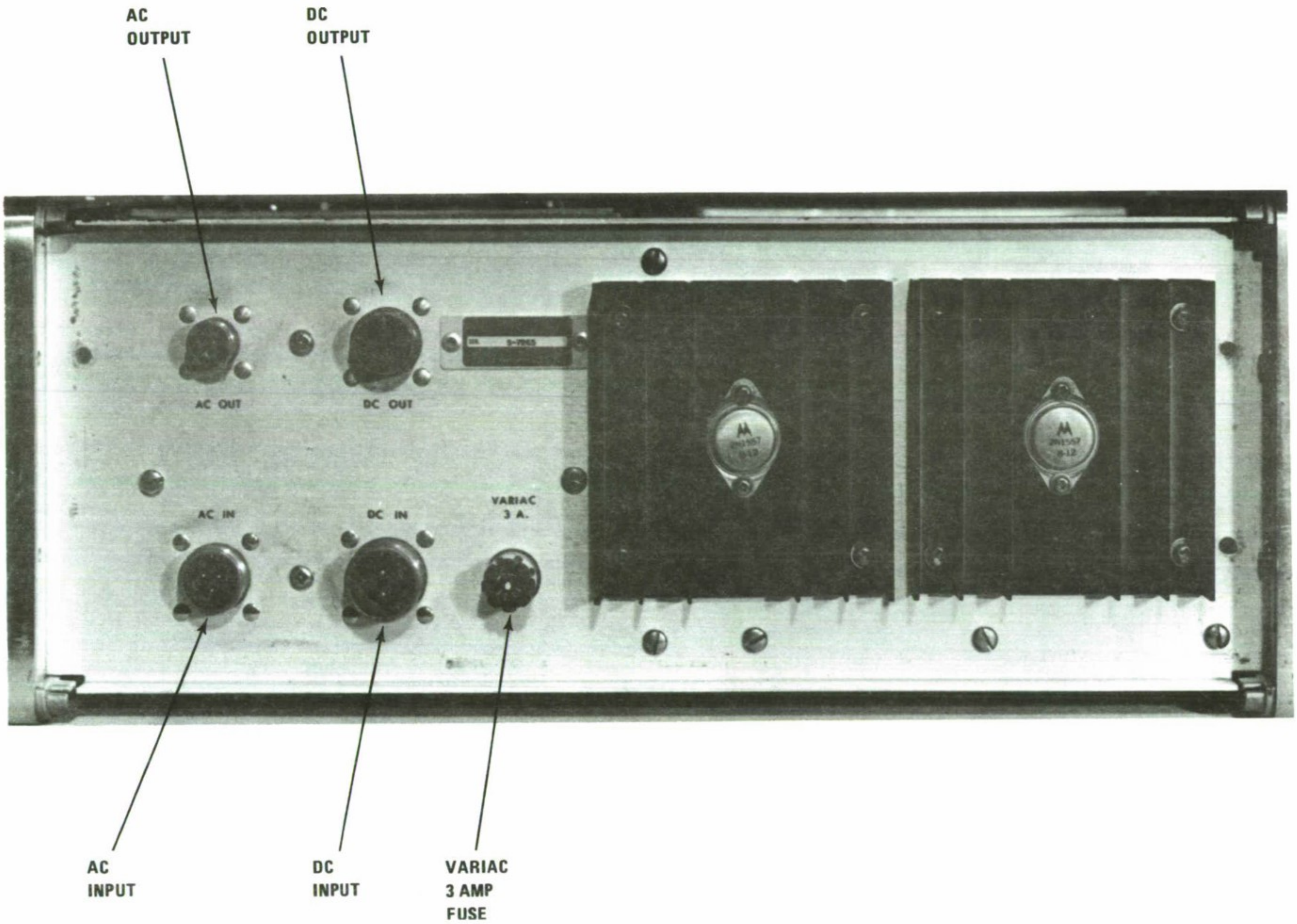


Figure 5-7A HP K02-5060A Rear Panel

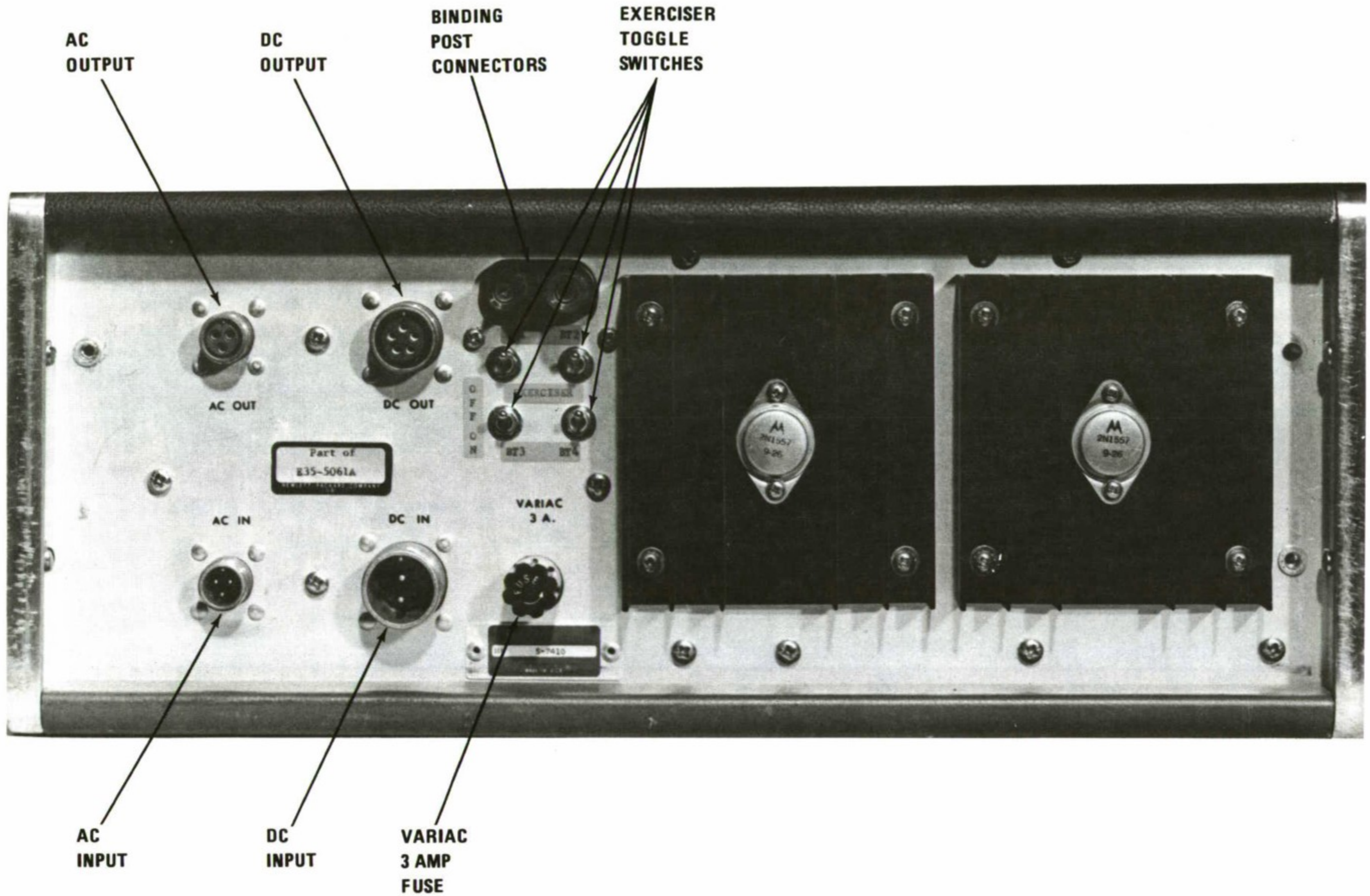


Figure 5-7B HP K24-5060A Rear Panel

5.2.2 Unpacking and Inspection

Unpack the instrument and inspect for physical damage. If any damage is found or if the instrument does not meet specifications, contact NAVOBSY immediately for guidance.

5.2.3 Installation

If it is not shipped as part of a cesium standard system, the instrument is ready for bench operation. To convert for rack mounting, see section 2, paragraph 2.3 of the Hewlett Packard Standby Power Supply K02-5060A Operating and Service Manual.

The instrument is shipped with batteries installed but discharged. The batteries must be charged for 24 hours under normal load conditions to assure 7 hours of standby time. To charge the batteries, perform the following procedure:

a. Set the POWER switch to match the external power source BEFORE connecting external power.

b. Set the ac voltage control fully counterclockwise to zero. Set the DC CHECK switch to OUTPUT.

c. Ensure that load is set for 230 volt operation and place the K02-5060A and load beside each other.

d. Remove the top cover of the K02-5060A.

e. Connect the DC OUT and AC OUT jacks on the K02-5060A back panel to the EXT DC and AC LINE input jacks on the load. Polarized plugs on the cables prevent connection errors. Do not use the AC line cord for the load.

f. Set the four BATTERY DISCONNECT SWITCHES inside the top of the K02-5060A to ON.

g. Connect the K02-5060A to the power source. The AC ON lamp will light.

h. Turn the ac voltage control slowly clockwise until the dc ammeter indicates 0. Do NOT leave the ac voltage control at its original 0 setting after the power source is connected.

i. The K02-5060A batteries are now being fast charged. They should be fully charged in approximately 24 hours. During this period, periodically readjust the ac voltage control to maintain a 0-ampere dc meter reading.

j. At the end of 24 hours, adjust the ac voltage control for +0.6 amp, as indicated on the dc ammeter, to maintain charges at their current level.

k. Verify that all individual battery voltages are within ±0.1 V dc of each other by setting the DC CHECK switch to each in turn. The output voltage on the dc voltage meter should read 26 V dc.

CAUTION

Do NOT leave the batteries on fast charge for more than 28 hours. Excessive heat will build up and damage the batteries.

5.2.4 Operation

5.2.4.1 Operating Precautions

a. Set the VARIAC ac voltage control to 0 before connecting or removing power, but do NOT operate at this setting.

b. Do NOT change the POWER switch setting with power on.

c. Set BATTERY DISCONNECT SWITCHES inside top cover to OFF when K02-5060A is not in use.

5.2.4.2 Turn-On Procedure

a. Set VARIAC ac voltage control to 0. Set POWER switch to match power source.

NOTE

To operate with 6 or 12 V dc primary power sources, 6 V source must supply 18-20 amperes and 12 V source must supply 9-10 amperes.

b. Verify that load is properly connected and set for 230 V ac power operation.

c. Set BATTERY DISCONNECT SWITCHES to ON.

d. Set DC CHECK to each position and verify a 26 V dc reading for each. With DC CHECK set to OUTPUT, verify ammeter reads on upward side of 0. The individual batteries should have ammeter readings downward of 0.

e. Connect primary power. AC ON lamp will light. For 6 V input operation, it may be necessary to press CONVERTER START 6V DC.

f. Set DC CHECK switch to OUTPUT. Adjust VARIAC ac voltage control for an ammeter indication of 0.6.

5.2.5 Maintenance

All meters and indicator light should be checked periodically (with DC CHECK in all positions) to ensure normal readings.

The batteries should be checked monthly for signs of corrosion or leaks. If signs of deterioration are visible, replace the batteries promptly. When the external power source has been very low, batteries must be fast charged to restore full standby capacity. They must also be fast charged following any period of standby operation.

5.2.5.1 Battery Replacement

a. Remove all input power.

b. Remove top and bottom covers.

c. Set BATTERY DISCONNECT SWITCHES to OFF.

d. Remove 4 mounting bolts from each battery of upper pack.

e. Carefully unsolder the black wire (-) from each battery.

f. Carefully unsolder the red wire (+) from each battery. Be sure wires do not short to chassis or each other.

g. Carefully lift batteries from instrument.

h. Reinstall the upper batteries with vent holes facing up by reversing steps d to g.

CAUTION

UNSOLDER black wire (-) first and red wire (+) last. SOLDER red wire (+) first and black wire (-) last.

i. Repeat steps a to h to replace the lower batteries. Vent holes should face the top of the instrument.

j. When all batteries are installed, connect input power and turn BATTERY DISCONNECT SWITCHES to ON. Replace covers.

CHAPTER 6

PORTABLE CLOCK OPERATIONS

Cesium beam clocks, calibrated to the Master Clock at the Naval Observatory, are periodically brought to PTTI field stations for comparison to and calibration of the field station clocks. These portable clock visits are the most reliable means of transferring precise time available. All other time transfer methods require initial and periodic system calibrations and/or validations from external sources (most often from portable clocks). Portable clock visits are also used to check dissemination systems (such as LORAN-C and satellites), to establish system and equipment delays, and to validate time-keeping ability and traceability.

To request a portable clock visit, write to:
Precise Time Operations Officer
Time Service Division
U.S. Naval Observatory
Washington, D.C. 20390

The following procedures are written from the standpoint of a portable clock from NAVOBSY visiting and synchronizing a clock at a PTTI field station. These procedures are also applicable to the case of a portable clock that is brought to a PTTI field station to be synchronized and certified.

6.1 MEASUREMENT PROCEDURES

Portable clock measurements should be made immediately on arrival at the field station and again right before departure. For long visits, measurements should be made on arrival, daily thereafter, and immediately prior to departure.

6.1.1 Required Equipment

To make portable clock measurements, the following equipment must be available:

a. A frequency standard to be measured (usually a cesium beam clock)
b. A reference cesium beam clock (usually the portable clock)

c. A reliable power supply (the HP K02-5060A Standby Power Supply will be used with the portable clock during transit)

d. An electronic computer (preferably with digital voltmeter)

e. An oscilloscope

f. Field Measurement PTTI Data Sheets.

6.1.2 Field Measurement PTTI Data Sheet (NAVOBSY PTTI Form TS-1, as revised, or comparable)

Before making any measurements, fill in the upper portion of the Field Measurement PTTI Data Sheet (figure 6-1). Be sure to include:

a. Activity and location

b. All members of the portable clock team, station personnel, and other interested parties present with each individual's activity following his name

c. Measured and reference clock designations (make certain any given clock always maintains the same designation)

d. Measured and reference oscillator manufacturer, model number, and serial number

e. Measured and reference clock manufacturer and model number

f. Complete mailing addresses to which original and copies of the Calibration Certificate should be mailed (the original should go to the agency responsible for the clock)

g. Compare hours, minutes, and seconds of the time display on the measured and reference clocks. Check YES if they agree. If they don't agree, check NO and explain in REMARKS.

h. Perform a Portable Clock Tick Check as follows:

1. Connect the portable clock 1 pps output to the counter START input via a 50-ohm impedance load. The impedance load will reduce the severe ringing of the 1 pps output.

2. Adjust the counter trigger levels for +0.4 V and a positive slope.

3. Connect the clock 100 kHz output to the counter STOP input.

4. Set the STOP input voltage level to 0 volts. To verify this setting, switch the SLOPE control alternately to positive and negative and adjust the voltage level until the counter reading changes exactly 5 μsec when the slope is reversed.

PTTI Form TS–1

FIELD MEASUREMENT PTTI DATA SHEET

Activity & Location:

Personnel Making Measurement:

Time Standard		Measured Clock	Reference Clock
Clock Designation			
Osc.	Manufacturer		
	Model No.		
	Serial No.		
Clock	Manufacturer		
	Model No.		
1PPS	Polarity & Voltage		
	Slope		
	Input Impedance		

Time Display Agreement — Remarks

Hours ☐ Yes ☐ No ____________

Minutes ☐ Yes ☐ No ____________

Seconds ☐ Yes ☐ No

PORTABLE CLOCK TICK CHECK
(1 pps to 100 kHz crossover)

Positive-going 0 volt crossing

☐ Yes ☐ No

Day/Mon/Yr(ZULU) ____________

Hours/Mins(ZULU) ____________

PC – CS = ____________ μsec

Calibration Certificate Mailing Addresses:

ORIGINAL:

_ _ _ _ _ _ _ _ _ _ _ _ _ _

COPIES TO:

_ _ _ _ _ _ _ _ _ _ _ _ _ _

1 PPS Sketch & Characteristics:

Amplitude: ________ volts, into ________ ohms

Polarity: ________ rise time ________ μsec

Pulse Length: ________ μsec

PTTI FIELD MEASUREMENT DATA

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Y	Y	Y	Y																																											
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Figure 6-1 Field Measurement PTTI Data Sheet (Sheet 1 of 2)

FIELD MEASUREMENT PTTI DATA SHEET

Activity & Location:	Personnel Making Measurement:
TIME STANDARDS LABORATORY AGMC, NEWARK AFS, OHIO	LAYANCEAU (USNO) GOFF (AGMC)

Time Standard		Measured Clock	Reference Clock
Clock Designation		AGMC/PRI	PC527
Osc.	Manufacturer	H/P	H/P
	Model No.	5060A	H29-5061A
	Serial No.	320-00236	527
Clock	Manufacturer	H/P	H/P
	Model No.	H20-115BR	OP-03
1PPS	Polarity & Voltage	+4.0	+0.4
	Slope	POS	POS
	Input Impedance	100K	50 Ω

Time Display Agreement — Remarks

- Hours [x] Yes [ ] No
- Minutes [x] Yes [ ] No
- Seconds [x] Yes [ ] No

PORTABLE CLOCK TICK CHECK
(1 pps to 100 kHz crossover)

Positive-going 0 volt crossing [x] Yes [ ] No

Day/Mon/Yr(ZULU) 30 DEC 72

Hours/Mins(ZULU) 1940

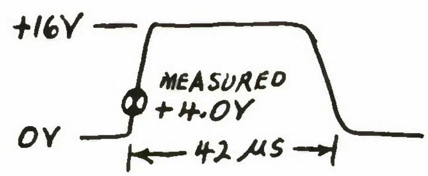
PC – CS = 5.3 μsec

Calibration Certificate Mailing Addresses:

ORIGINAL: AGMC/MLOS
ATTN: MR. A. ALPERT
NEWARK AFS
NEWARK, OH 47352

COPIES TO:

1 PPS Sketch & Characteristics:



Amplitude: 16.0 volts, into 100K ohms

Polarity: POSITIVE rise time 0.3 μsec

Pulse Length: 42 μsec

PTTI FIELD MEASUREMENT DATA

Cols 1–4	Cols 5–24	Cols 17–20	Cols 25–30	Cols 31–37	Cols 38–47
YYYY	NEWARK AFS AGMC				
30 DEC 72					
PC527					
	AGMC/PRI	7.5	15.0	301925 Z	DEC 72
	AGMC/PRI	7.7	15.4	021310 Z	JAN 73
		.	.	Z	
		.	.	Z	
		.	.	Z	
		.	.	Z	
NOTES					
.					
.					
.					

Figure 6-1 Field Measurement PTTI Data Sheet (Sheet 2 of 2) Sample

5. Record the counter reading with the slope in the positive position on the data sheet as PC - CS = ____ μsec.

NOTE

This reading is the time difference between the 1 pps and the 0 volt crossing of the positive-going 100 kHz sine wave. A variation in this valve indicates a possible shift in the 1 pps. Large or erratic changes indicate a possible divider malfunction in the oscillator. This measurement does not provide any information as to possible clock jumps in increments of 10 microseconds or multiples of 10 microseconds. Therefore, it cannot be used as an indicator of clock health or performance outside a 10-microsecond region of validity. In other words, a bad tick to phase measurement indicates a problem in the clock, a good tick to phase measurement does not guarantee that there are no problems in the clock.

i. Determine the characteristics of the measured clock 1 pps as follows:

1. Connect the measured clock 1 pps output to the oscilloscope input.

2. Using the oscilloscope internal trigger, adjust for the optimum 1 pps display and record the following in the middle section of the data sheet:

a) A reasonably accurate and proportioned sketch of the complete 1 pps display

b) The 1 pps amplitude in volts

c) The input impedance in ohms

d) The 1 pps polarity

e) The total rise time of the 1 pps in microseconds

f) The 1 pps length in microseconds.

j. List the date, month, year, hours, and minutes (all ZULU).

k. Perform and record the clock measurements.

l. Explanation of the measurement data recording format can be found in chapter 15.

6.2 CLOCK MEASUREMENTS

6.2.1 Equipment Set-Up (Figure 6-2)

a. Connect the external oscillator input jack on the electronic counter to the 5 MHz or 1 MHz output jack on the portable reference clock. Make sure that any switches pertaining to the counter time base are set for external input.

b. Connect the portable reference clock 1 pps output, via a 50-ohm impedance load, to the electronic counter input A (the START input).

c. Connect the 1 pps output of the station clock to be measured, via a 50-ohm impedance load, to the electronic counter input B (the STOP input). The 50-ohm loads are necessary to reduce the severe ringing of the 1 pps outputs.

d. Adjust the counter trigger controls for the correct pulse voltage level, slope, and polarity. Record the resulting readings on the data sheet.

1. The portable reference clock input level should be set at +0.4 V with a positive slope.

2. The input level of the station clock to be measured may be set at the level specified by station personnel, at the same level as the reference clock, or at an appropriate level as determined from 6.1.2.i.

6.2.2 Clock Readings

The reading displayed on the electronic counter should be less than 500,000 μsec. If it is greater than 500,000 μsec, reverse the 1 pps inputs to the counter. If the portable reference clock is connected to the START input jack and the station clock being measured is connected to the STOP input jack (as originally set up), record the smaller reading without a sign in the bottom section of the data sheet. If it is necessary to reverse the 1 pps inputs, record the resulting smaller reading with a minus (-) sign on the data sheet.

The counter reading recorded is the time difference between the portable reference clock and the station measured clock, i.e., REFERENCE CLOCK - MEASURED CLOCK = TIME DIFFERENCE. This reading can be added to the time difference between the NAVOBSY Master Clock and the portable reference clock to find

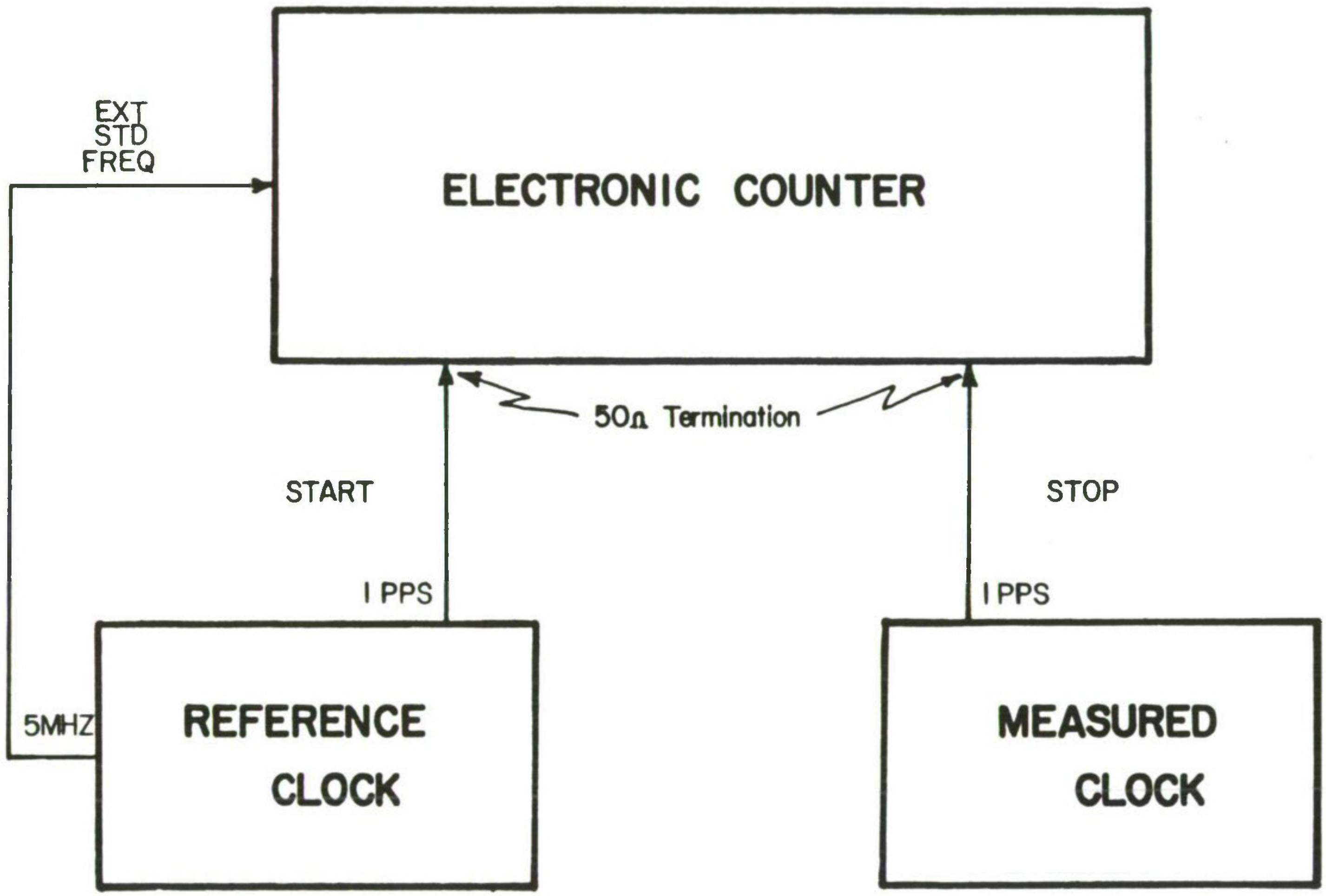


Figure 6-2 Portable Clock Equipment Set-Up

the time difference between the Master Clock and the station clock. Algebraically:

	REFERENCE CLOCK	- MEASURED CLOCK	= TIME DIFFERENCE
+	NAVOBSY MASTER CLOCK	- REFERENCE CLOCK	= TIME DIFFERENCE
=	NAVOBSY MASTER CLOCK	- MEASURED CLOCK	= TIME DIFFERENCE

The time difference between the NAVOBSY Master Clock and the portable clock is determined by interpolation from the calibrations made at NAVOBSY before and after the portable clock trip (figure 6-3). The utmost care must be exercised to ensure that the addition is carried out properly and the correct sign is used with each value.

It is also possible to use a station clock as a reference clock and to measure any other clock against it. To determine the difference between the measured clock and the NAVOBSY Master Clock in this case, use the time difference values listed in the NAVOBSY Time Service Announcement, Series 16, for the station reference clock as follows.

NOTE

These extrapolations are not valid if any discontinuities have occurred in the operation of the station reference clock after the dates of the certified measurements.

a. Plot the last three values given in the Time Service Announcement on graph paper and draw an extended line through these points. For example:

NAVOBSY MASTER CLOCK - STATION REFERENCE CLOCK	= 5.7 μsec	@ 0300Z,	13 MAR 73
" " " - " " "	= 6.3 "	@ 0700Z,	21 MAR 73
" " " - " " "	= 7.0 "	@ 0500Z,	1 APR 73

would be extrapolated in a graph as in figure 6-4.

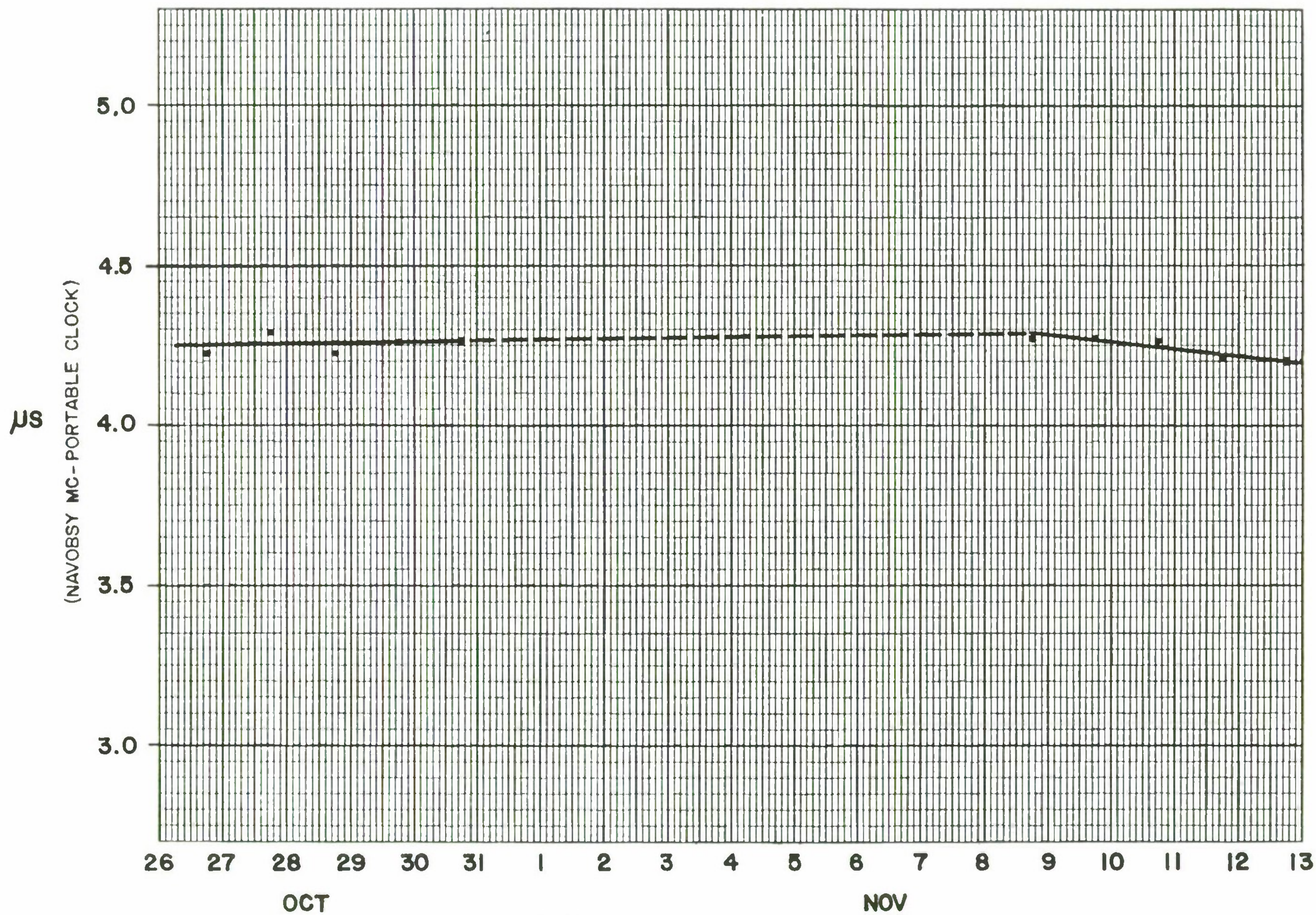


Figure 6-3 Clock Calibration Graph - Precalibration

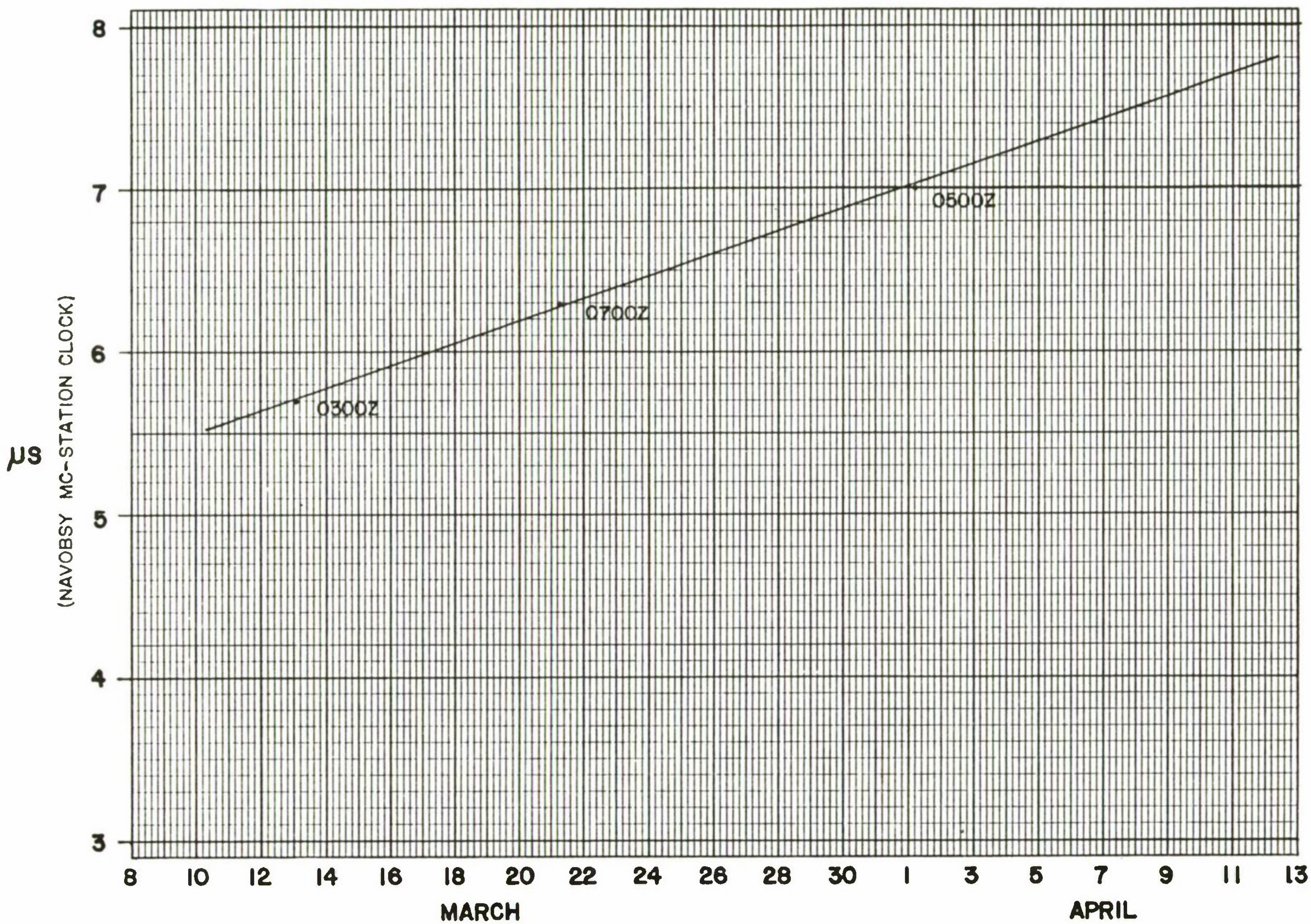


Figure 6-4 Clock Calibration Graph - Postcalibration

b. The algebraic comparison between the measured clock and the NAVOBSY Master Clock is made with the same equation as before, except that now the station clock is the reference clock. For example:

If STATION REFERENCE CLOCK - MEASURED CLOCK = -13.2 μsec @ 1400Z, 9 APR 73, as determined from the reading taken with an electronic counter, and from the graph extrapolation (see figure 6-4) NAVOBSY MASTER CLOCK - STATION REFERENCE CLOCK = 7.6 μsec @ 1400Z, 9 APR 73, then:

	STATION REFERENCE CLOCK	- MEASURED CLOCK	= -13.2 μsec
+	NAVOBSY MASTER CLOCK	- STATION REFERENCE CLOCK	= 7.6 μsec
=	NAVOBSY MASTER CLOCK	- MEASURED CLOCK	= - 5.6 μsec

For convenience, the values in the Time Service Announcement, Series 16, should be plotted on a graph when received and kept at the station for ready reference.

When all measurements and all calculations have been done, send the completed Field Measurement PTTI Data Sheet and a copy of all calculations to the following address:

Superintendent
U.S. Naval Observatory
Attn: Time Service Division
Washington, D.C. 20390

CHAPTER 7
LORAN-C SYSTEM

The LORAN-C system is composed of several networks of fixed stations, called chains, all of which transmit groups of radio pulses at a carrier frequency of 100 kHz. Each chain consists of a master station and two or more slave stations separated from each other by several hundred miles. All of the stations transmit groups of eight phase-coded pulses, separated from each other by one millisecond. The master stations transmit an additional ninth pulse (the master identifier) that is separated from the first eight pulses by two milliseconds. The stations are silent between pulse groups. Each LORAN-C chain transmits these groups of pulses at different repetition rates by which a specific chain can always be identified.

Within any given LORAN-C chain, the times of transmission of each slave station are delayed by different amounts so that, no matter where a receiver is located within the groundwave coverage of the chain, pulses from the master station will always be received first, followed in order by pulses from each successive slave station. The transmitted radio pulses are derived from atomic frequency standards at each station. The standards are adjusted and controlled to minimize time differences between stations. Thus, submicrosecond epoch time determinations and frequency measurements with an accuracy of several parts in 10^{12} are possible with one-day averaging.

The LORAN-C system is sychronized by and compared to the NAVOBSY Master Clock to maintain precise time throughout the system. The difference between the NAVOBSY Master Clock and each LORAN-C chain is published weekly in the NAVOBSY Time Service Announcement, Series 4. Corrections may be obtained daily by message (NAVOBSY Time Service Announcement, Series 5), by telephone (202-254-4662 or Autovon 294-4662), or by computer (202-254-4080 or Autovon 294-4080).

Except for very long overland paths, LORAN-C groundwaves have a precision of 0.2 μsec and an accuracy of 0.8 μsec, if the corrections in the NAVOBSY Time Service Announcement, Series 4, are applied. Cycle identification errors could add ±10 μsec to these figures. The LORAN-C chains are generally kept to within 5 μsec probable error of UTC(USNO). Efforts are being made to improve this to about 1 μsec probable error.

The precision of LORAN-C skywaves for night to night measurements at the same time is 3 μsec. Cycle identification (±10 μsec) is more difficult using skywaves than using groundwaves. Accuracy of the skywaves is affected by the uncertainty of which mode (hop) is being received. This may cause about 30-50 μsec error in absolute values. Skywaves, however, greatly increase the range of a LORAN-C station.

A listing of LORAN-C stations is given in table 7-1. For details of the coordinates, emission power and delays, times of coincidence, etc., refer to the latest NAVOBSY Time Service Announcement, Series 9.

7.1 RECEIVER SET-UP AND OPERATION

The Austron Model 2000C LORAN-C Receiver (figures 7-1 through 7-4) should be connected to related station equipment as shown in figure 7-5. For detailed installation instructions, consult the manufacturer's manual for each piece of equipment.

NOTE

There are several generations of Austron 2000C receivers. The following instructions are written for the latest generation. Consequently, there are instances where a specific instruction may not apply exactly to your receiver. Consult your operator's manual for clarification.

The LORAN-C receiver must be connected to 115/230 V ac external power. A standby dc power source for the receiver, capable of supplying 22 to 32 V dc at 0.7 amp, is highly recommended.

The antenna should be mounted on a rooftop or in some clear area away from trees, buildings, etc., that could cause interference. It should be kept away from transformers, power lines, and high power RF sources.

Table 7-1 LORAN-C Station List

GROUP REPETITION RATES (μS)	MASTER	WHISKEY	X-RAY	YANKEE	ZULU
49900	Johnston Island, (Sand Island)		Upolo Point, Hawaii	Kure Island,	
59300	Caribou, ME*		Nantucket, MA*	Cape Race, Newfoundland, Canada*	Fox Harbor, Canada
59900	Williams Lake, BC, Canada		Shoal Cove, AK*	George, WA*	Port Hardy, BC, Canada
79300	Angissoq, Greenland	Sandur, Iceland*	Ejde, Faroe Islands*		Cape Race, Newfoundland, Canada*
79600	Tok, AK		Narrow Cape, Kodiak Is., AK*	Shoal Cove, AK*	
79700	Ejde, Faroe Islands*	Sylt, F.R. Germany	Boe, Norway	Sandur, Iceland*	Jan Mayen, Norway
79800	Malone, FL*	Grangeville, LA	Raymondville, TX	Jupiter, FL	Carolina Beach, NC*
79900	Sellia Marina, Italy		Lampedusa, Italy	Kargabarun, Turkey	Estartit, Spain
89700	Dana, IN*	Malone, FL*	Seneca, NY*	Baudette, MN	
99400	Fallon, NV	George, WA*	Middletown, CA	Searchlight, NV	
99600	Seneca, NY*	Caribou, ME*	Nantucket, MA*	Carolina Beach, NC*	Dana, IN*
99700	Iwo Jima, Bonin Islands, Japan	Marcus Island, Japan	Hokkaido, Japan	Gesashi, Japan	Yap Island, USA Trust
99900	St. Paul, Pribilof Is., AK		Attu, AK	Port Clarence, AK	Narrow Cape, Kodiak Is., AK*

*Denotes dual-rated stations.

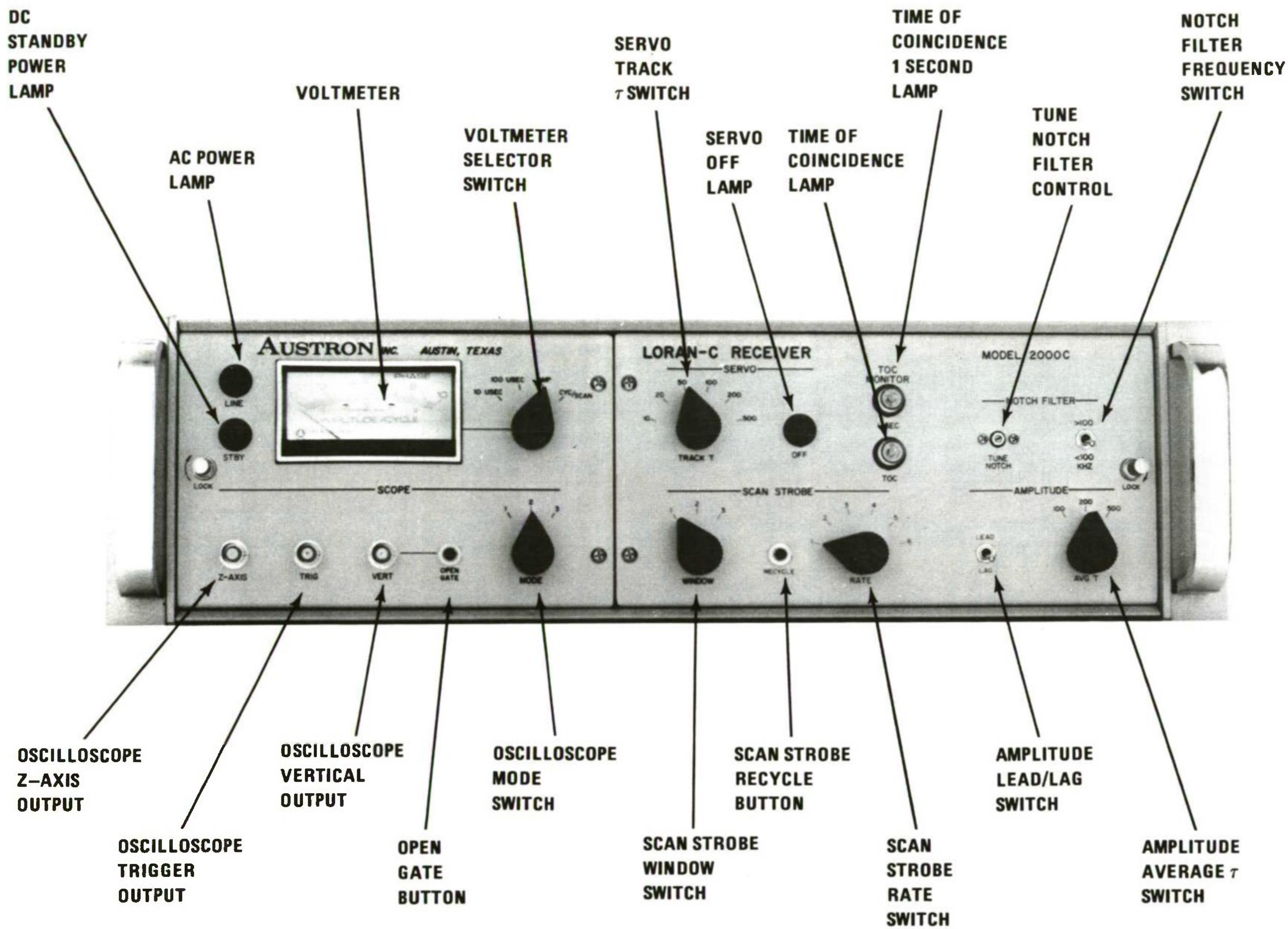


Figure 7-1 Austron 2000C Front Panel

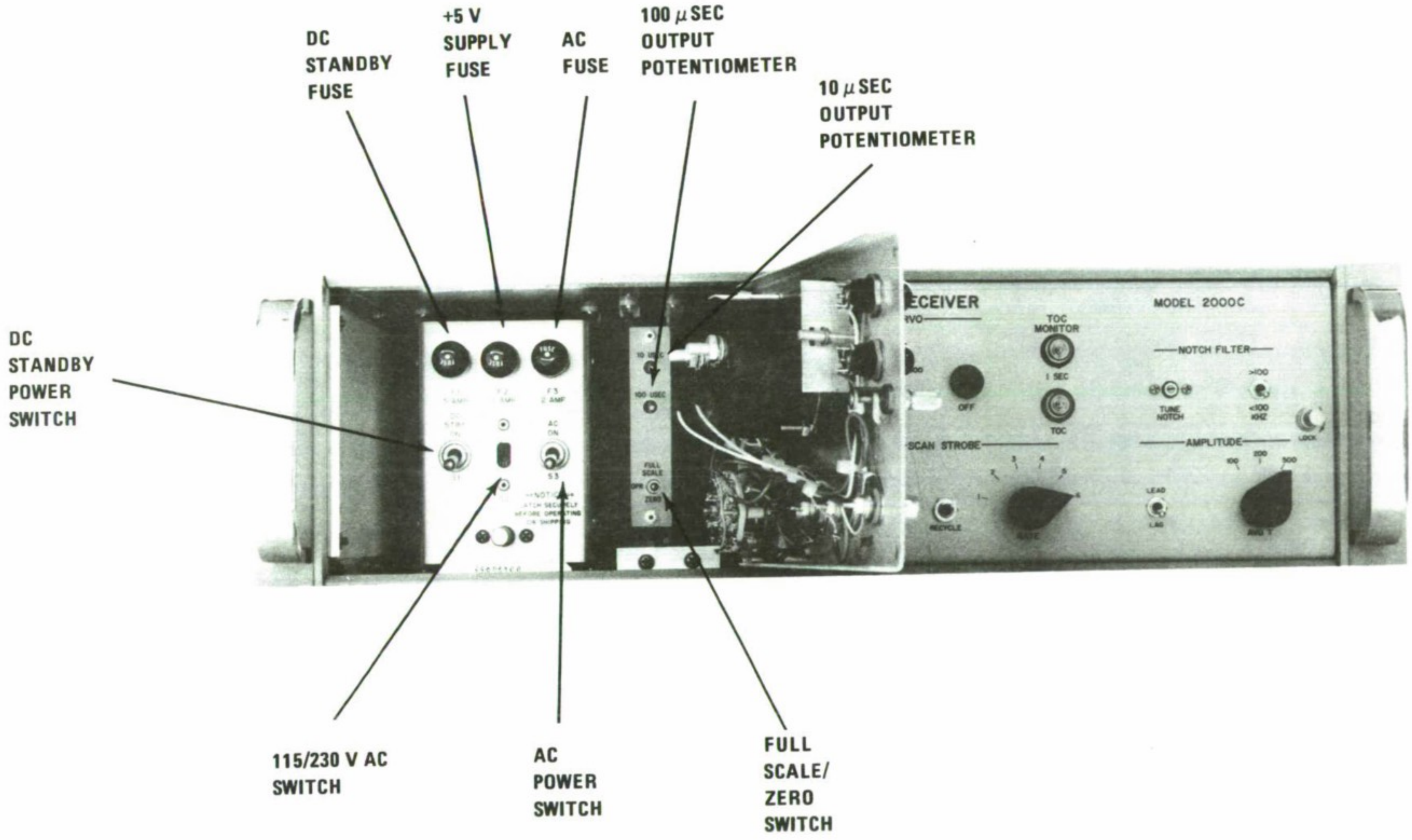


Figure 7-2 Austron 2000C Inside Left Front Cover

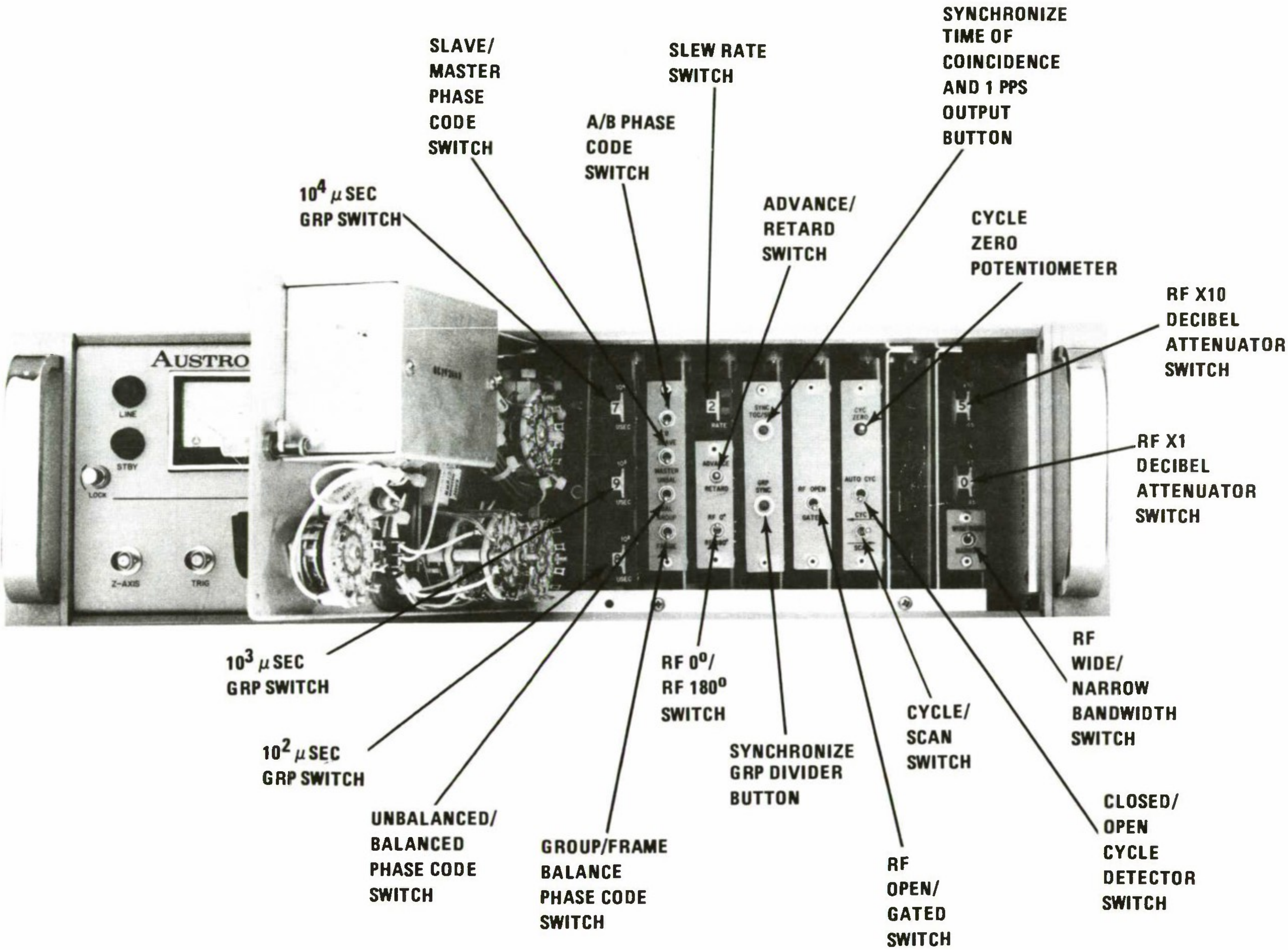


Figure 7-3 Austron 2000C Inside Right Front Cover

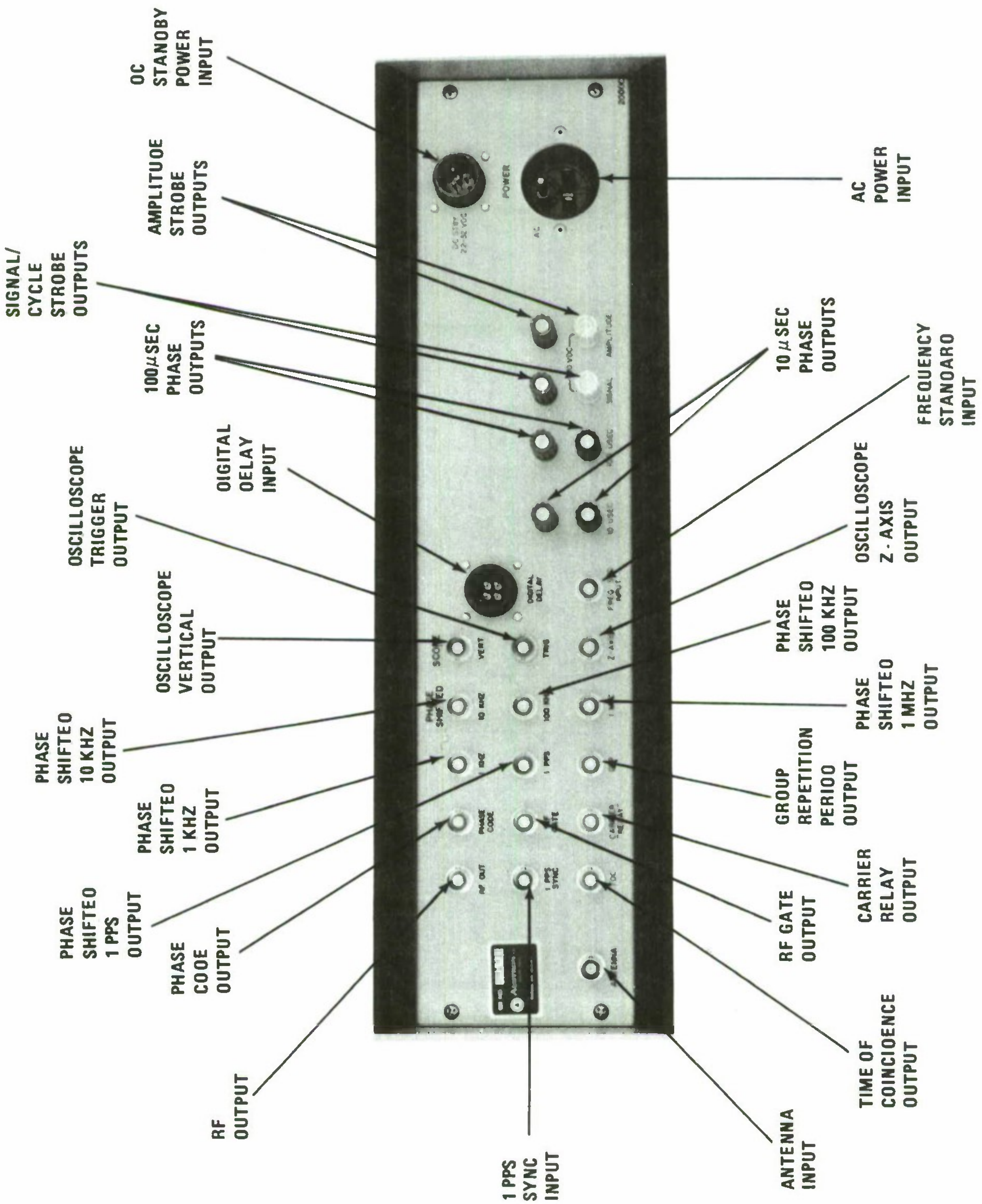


Figure 7-4 Austron 2000C Rear Panel

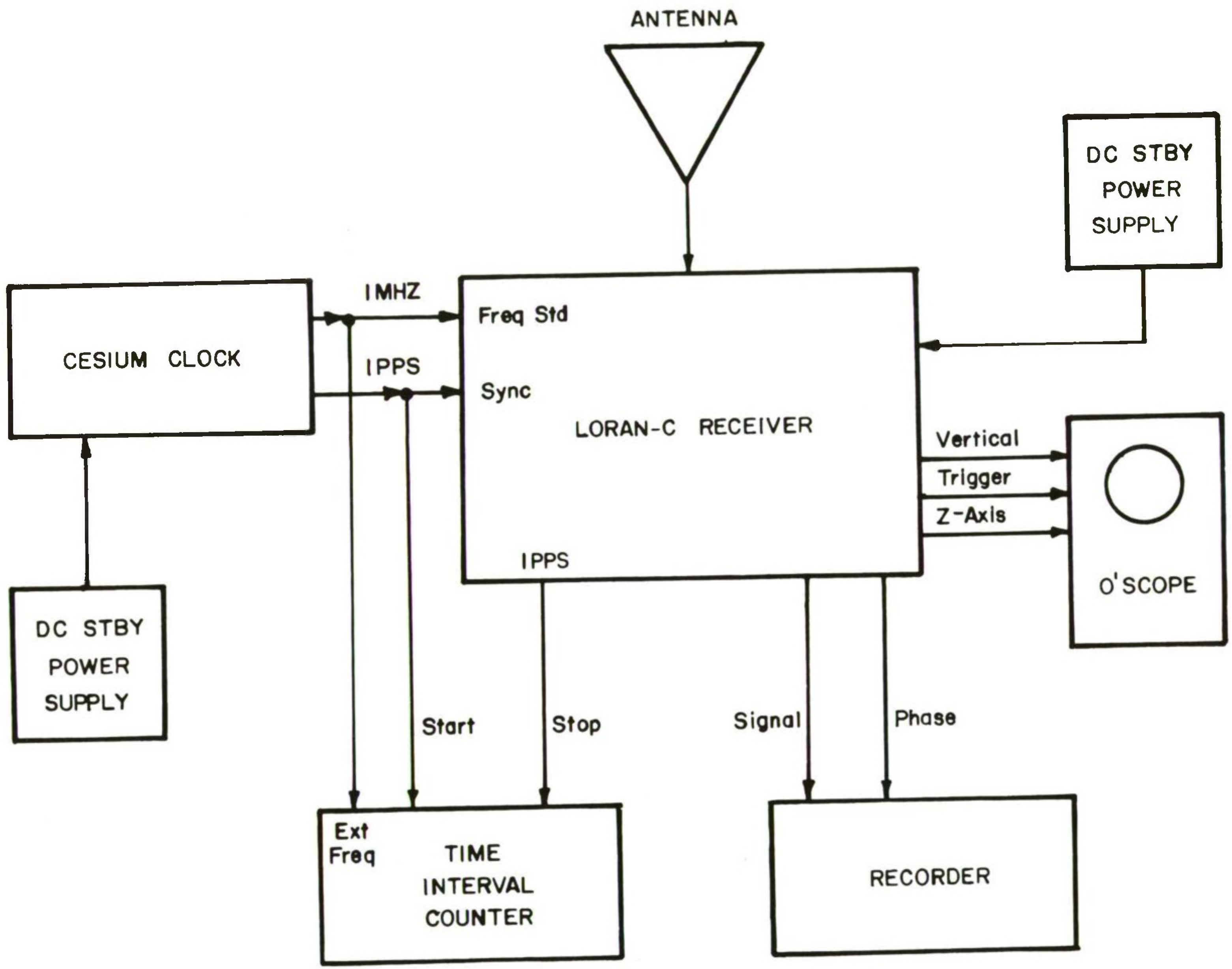


Figure 7-5 LORAN-C Receiver Set-Up

The following is an abbreviated procedure for locking the receiver to a LORAN-C signal. It is intended for those who are somewhat familiar with LORAN-C. A more detailed procedure can be found in the receiver instruction manual.

a. Set the LORAN-C receiver controls as follows:

1. Oscilloscope mode - 1
2. RF attenuator switches - about 20 dB
3. RF open/gated switch - open
4. Slew rate switch - 6 (fast)
5. GRP switches - period of desired LORAN-C chain.

b. Set the oscilloscope controls as follows:

1. Vertical sensitivity - about 0.2 V/division
2. Trigger source - external
3. Trigger coupling - dc or ac
4. Trigger slope - positive
5. Trigger level - positive
6. Sweep mode - normal
7. Sweep speed - about 10 msec/division.

c. Using the advance/retard switch, slew the eight pulses to the intensified area on the oscilloscope. Set the scope at 1 msec/division for the final adjustment.

d. On the receiver, set the oscilloscope mode switch to 2, the RF open/gated switch to gated, and the slew rate control to a slower rate (4 or 5).

e. Set the oscilloscope sweep speed to 20 μsec/division. Using the advance/retard switch, slew the display to position the beginning of the pulse in the intensified area.

f. Decode the pulse carrier with the slave/master and A/B switches and set the following receiver controls:

1. Oscilloscope mode switch - 3
2. RF 0°/RF 180° switch - appropriate position (0° if antenna is oriented correctly)
3. Meter selector switch - amplitude.

g. Using a very slow slew rate (2 or 3), slew the intensified tracking point to a zero crossing. Adjust the RF attenuator such that the servo off lamp goes off and the meter reads near the set point.

Recognizing and verifying the tracking point location can be quite difficult. It may require between several hours and several days of recording, using different combinations of time constants under various propagation conditions, before a determination can be made with any confidence. Once made, however, the time difference measured on the time interval counter becomes a standard by which system performance is measured. Any variations in day to day readings, or discontinuities greater than 0.5 microseconds are indications of possible problems and should be investigated and reported.

7.2 TIME OF COINCIDENCE CALCULATION AND SYNCHRONIZATION

In a synchronized LORAN-C chain, the beginning of the first pulse of one of the groups transmitted by the master station will occur at the start of a NAVOBSY Master Clock second. This is called a reference pulse and the Master Clock second that it coincides with is a null second or time of coincidence (TOC). The interval between successive null seconds is a function of the repetition rate and is therefore different for each LORAN-C chain. NAVOBSY publishes TOC tables in Time Service Announcement, Series 9.

To derive time from LORAN-C signals, the precise time of arrival of the LORAN-C pulse at the receiver must be determined by identifying a particular cycle and comparing a zero crossover of that cycle to the reference clock. The third cycle is generally preferred for this purpose because it is less subject to distortion than earlier and later cycles. The zero crossover at the end of this third cycle is called the tracking point (figure 7-6). In general, the tracking point will be offset from the beginning of a TOC by an amount called the total timing delay, which consists of propagation delay, emission delay, receiver delay, and a cycle correction. (An explanation of these can be found in the receiver manual.) Any local station clock can be set to the NAVOBSY Master Clock by synchronizing the leading edge of the one second output from the clock to the tracking point on the first LORAN-C pulse occurring after a TOC, then advancing the output of the clock by an amount equal to the total timing delay.

The TOC for any LORAN-C pulse can be found for any day using the tables in Time Service Announcement, Series 9. From table 1 in Series 9, find the

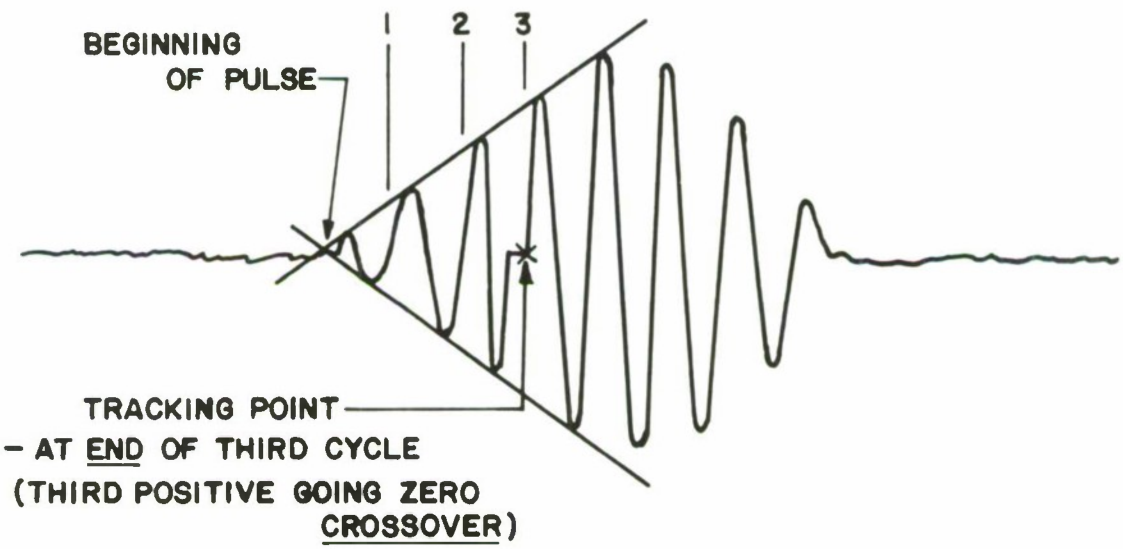


Figure 7-6 Tracking Point Identification on LORAN-C Pulse Envelope

hour, minute, and second listed for the desired day. Add this to the values from Series 9 table 2 that are closest to the present time. The result is the TOC. For example:

Use the sample Series 9 tables (figures 7-7 and 7-8) to determine a TOC near 1800 UT on 15 January 1980. The first TOC of the day, listed in table 1, is:

H	M	S
00	03	54

For times near 1800 UT, table 2 lists:

H	M	S
17	54	51
17	59	00
18	03	09

Adding the table 1 value to those in table 2 gives:

H	M	S
17	58	45
18	02	54
18	07	03

The next TOC after 18H 00M 00S on 15 January 1980, then, will be at 18H 02M 54S.

To synchronize the 1 pps output of the LORAN-C receiver to the NAVOBSY Master Clock, calculate the next TOC. Less than one second before the TOC, press the SYNC/TOC/SEC button behind the access door on the front panel of the receiver. Release the button after the TOC has passed. The LORAN-C pulse will now be synchronized to the Master Clock and the counter should indicate the time of arrival of the LORAN-C pulse in relation to the Master Clock.

7.3 NOTES ON LORAN-C

When operating the LORAN-C system, keep the following items in mind:

a. The receiver attenuator must be set so the meter reads above the set mark and below full scale with the meter selector switch in AMP x 10 position at noon, local time.

TABLE 1
FIRST TOC FOR EACH DAY

TIMES OF COINCIDENCE (NULL) EPHEMERIS

NORTHEAST USA (9960) LORAN-C

99,600 MICROSECONDS/PERIOD

DATE 1980	TIME H	M	S	DATE 1980	TIME H	M	S	DATE 1980	TIME H	M	S
JAN 1	0	3	12	FEB 1	0	0	36	MAR 1	0	2	3
2	0	3	15	2	0	0	39	2	0	2	6
3	0	3	18	3	0	0	42	3	0	2	9
4	0	3	21	4	0	0	45	4	0	2	12
5	0	3	24	5	0	0	48	5	0	2	15
6	0	3	27	6	0	0	51	6	0	2	18
7	0	3	30	7	0	0	54	7	0	2	21
8	0	3	33	8	0	0	57	8	0	2	24
9	0	3	36	9	0	1	0	9	0	2	27
10	0	3	39	10	0	1	3	10	0	2	30
11	0	3	42	11	0	1	6	11	0	2	33
12	0	3	45	12	0	1	9	12	0	2	36
13	0	3	48	13	0	1	12	13	0	2	39
14	0	3	51	14	0	1	15	14	0	2	42
15	0	3	54	15	0	1	18	15	0	2	45
16	0	3	57	16	0	1	21	16	0	2	48
17	0	4	0	17	0	1	24	17	0	2	51
18	0	4	3	18	0	1	27	18	0	2	54
19	0	4	6	19	0	1	30	19	0	2	57
20	0	4	9	20	0	1	33	20	0	3	0
21	0	0	3	21	0	1	36	21	0	3	3
22	0	0	6	22	0	1	39	22	0	3	6
23	0	0	9	23	0	1	42	23	0	3	9
24	0	0	12	24	0	1	45	24	0	3	12
25	0	0	15	25	0	1	48	25	0	3	15
26	0	0	18	26	0	1	51	26	0	3	18
27	0	0	21	27	0	1	54	27	0	3	21
28	0	0	24	28	0	1	57	28	0	3	24
29	0	0	27	29	0	2	0	29	0	3	27
30	0	0	30					30	0	3	30
31	0	0	33					31	0	3	33

Figure 7-7 Time Service Announcement, Series 9, Table 1 - First TOC for Each Day

TABLE 2
INTERPOLATIONS FOR ALL TOC'S IN A DAY
TIMES OF COINCIDENCE (NULL) EPHEMERIS
NORTHEAST USA (9960) LORAN-C

99,600 MICROSECONDS/PERIOD

H	M	S	H	M	S	H	M	S
16	36	0	19	22	0	22	8	0
16	40	9	19	26	9	22	12	9
16	44	18	19	30	18	22	16	18
16	48	27	19	34	27	22	20	27
16	52	36	19	38	36	22	24	36
16	56	45	19	42	45	22	28	45
17	0	54	19	46	54	22	32	54
17	5	3	19	51	3	22	37	3
17	9	12	19	55	12	22	41	12
17	13	21	19	59	21	22	45	21
17	17	30	20	3	30	22	49	30
17	21	39	20	7	39	22	53	39
17	25	48	20	11	48	22	57	48
17	29	57	20	15	57	23	1	57
17	34	6	20	20	6	23	6	6
17	38	15	20	24	15	23	10	15
17	42	24	20	28	24	23	14	24
17	46	33	20	32	33	23	18	33
17	50	42	20	36	42	23	22	42
17	54	51	20	40	51	23	26	51
17	59	0	20	45	0	23	31	0
18	3	9	20	49	9	23	35	9
18	7	18	20	53	18	23	39	18
18	11	27	20	57	27	23	43	27
18	15	36	21	1	36	23	47	36
18	19	45	21	5	45	23	51	45
18	23	54	21	9	54	23	55	54
18	28	3	21	14	3			
18	32	12	21	18	12			
18	36	21	21	22	21			
18	40	30	21	26	30			
18	44	39	21	30	39			
18	48	48	21	34	48			
18	52	57	21	38	57			
18	57	6	21	43	6			
19	1	15	21	47	15			
19	5	24	21	51	24			
19	9	33	21	55	33			
19	13	42	21	59	42			
19	17	51	22	3	51			

Figure 7-8 Time Service Announcement, Series 9, Table 2 - Interpolations for All TOCs in a Day

b. The receiver attenuator switch must be in detent; otherwise, no signal will pass to the detection stages. The signal must be visible on the oscilloscope.

c. Prescribed trigger levels should always be used on the electronic counter.

d. If the receiver loses lock, it should not be adjusted unless it can be verified that the transmitter is on the air and the receiver isn't relocking. In this case, slewing the receiver 1 or 2 microseconds will permit the servo to relock the receiver to a zero crossover.

e. Both the signal and phase should be recorded on the chart recorder. Abnormal steps in phase should be reported.

f. A record of all receiver and system delay measurements should be kept. The receiver delay should be placed on the receiver.

CHAPTER 8

HIGH FREQUENCY (HF) SYSTEMS[1]

This section describes two methods of using high frequency time transmissions to determine time of day or time interval to a resolution better than 1 millisecond (1000 microseconds). Under favorable propagation conditions, it is possible to establish time synchronization to better than 100 microseconds. The methods are: (1) direct trigger and (2) delayed trigger. Techniques used in the direct trigger method are fundamental to the second method. In each case, knowledge of path and equipment time delays is necessary for accurate results.

In order to achieve optimum results in any of these measurement methods, the following guidelines are recommended:

a. Carry out measurements at exactly the same time every day.

b. Avoid twilight hours when the ionosphere is the least stable.

c. Choose the highest frequency which provides consistently good reception.

d. Observe the received signals on the oscilloscope for a few minutes to establish the stability of propagation conditions and select that portion of the timing waveform that is most consistent.

8.1 DIRECT TRIGGER METHOD OF TIME SYNCHRONIZATION

a. The direct trigger method is the simplest and requires only the following equipment: (1) an oscilloscope with external sweep trigger and accurately calibrated time base, and (2) an HF receiver with audio output. Equipment connection is shown in figure 8-1.

b. A local clock pulse at a once per second rate is used to trigger the oscilloscope sweep. At some time during the sweep, the HF seconds pulse appears on the display. The time interval from the start of the sweep to the point where the HF tick appears is the total time difference between the local clock and the HF time signal. By subtracting the propagation time delay and the receiver time delay from the measured value, the local clock time error from the HF time signal can be determined. The equation used to determine time error at a receiving location is:

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[1]From NBS Note 668.

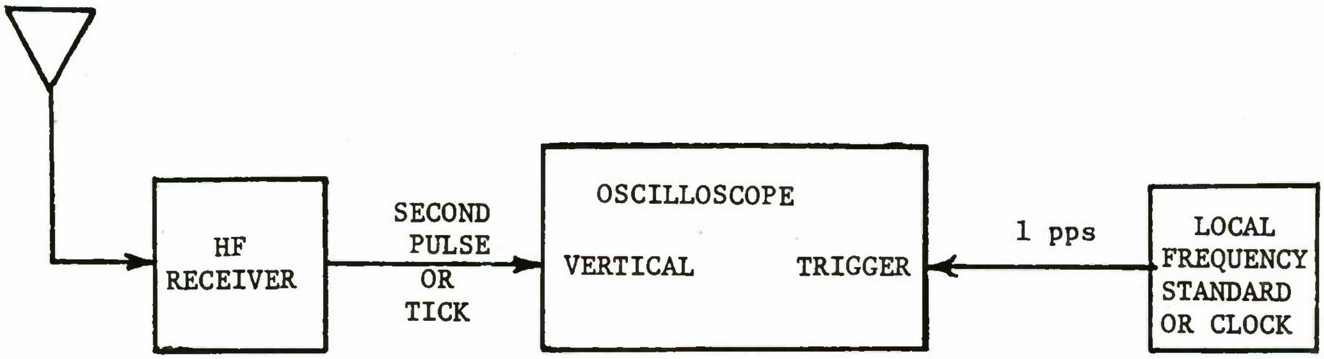


Figure 8-1 Block Diagram of Equipment Connection for Direct Trigger Method of Time Synchronization

Time Error = $t_r - t_t = TD - (TD_p + TD_r)$,

where

t_r = time of receiving station

t_t = time of transmitting station

TD = total time difference (measured)

TD_p = time delay (propagation)

TD_r = time delay (receiver)

c. To synchronize a local clock with the HF time signal, the local clock must be adjustable so its tick can be advanced or retarded. The receiver is tuned to the HF station with the oscilloscope sweep rate set at 0.1 s/division. The time tick will typically appear as a short burst of a 1-2 kHz sinusoid. If the received tick is less than five divisions (0.5 sec) from the left side of the scope display, the time of the local clock is early and it must be retarded until the time tick falls within the first division from the left side. If the local time tick is late, the received time tick will be heard before the sweep starts, appearing more than five divisions from the left side, and the local clock should be advanced until the tick appears within the first division from the left side. After the local seconds pulse has been properly adjusted within the first division (0.1 second in time), the sweep rate is increased to, say, 10 ms/division. Using this greater resolution, the local clock is adjusted until the leading edge of the pulse starts at a time equal to the propagation delay time plus the receiver delay time after the trigger.

d. The sweep rate should be expanded to the highest rate possible without allowing the total sweep time to become less than the combined progagation and receiver delay time.

e. Although the leading edge of the seconds pulse as broadcast from these stations is "on time," coincident with UTC, it is difficult to measure because of the slow rise time at the beginning of the burst and noise in the system. For this reason, the second zero crossover (first positive-going crossover) should be used and a cycle correction term (one period of the tick) included in the time error equation:

Time error = $t_r - t_t = TD \;\; (TD_p + TD_r + \text{cycle correction})$

where

cycle correction time = one period of the tick

As an example, assume an operator at a distant receiver location is interested in comparing his time to that of WWVH. The propagation and receiver delay times are determined to be 11.7 milliseconds and 300 microseconds respectively. Since the total delay is 12.0 milliseconds (11.7 ms + 0.3 ms), the oscilloscope sweep rate is set at 2 ms/division for a total sweep time of 20 ms--slightly greater than the propagation delay + receiver delay + 5 ms total. The second zero crossover of the tick is observed and measured at 12.5 ms after the sweep was triggered by the station clock.

From these data, the time at the receiver site, calculated with respect to the WWVH (UTC) time as broadcast, is:

Time Error = 12.5 - (11.7 + 0.3 + 0.833) = -0.333 ms

where

$TD = 12.5$ ms

$TD_p = 11.7$ ms

$TD_r = 0.3$ ms

The one-cycle correction (one period of the tick) for WWVH = 0.833 ms. This shows the clock at the receiver site to be 0.333 msec late with respect to WWVH.

It will be noted that if a receiving station is located at a distance greater than 3,000 km (1863 miles) from the transmitter, the propagation time will exceed 10 ms. This forces the user to use a scope sweep time of 2 ms/division and lowers the measurement resolution. The next section describes a method of measurement to overcome this difficulty. (The radio path delay works out to be about 5 μs per mile. At 1863 miles, the delay would be at least 9.315 ms. It is greater than this due to the fact that HF radio signals bounce off the ionosphere. The additional correction must be calculated on a case-by-case basis at the time measurements are taken.)

8.2 DELAYED TRIGGER METHOD OF TIME SYNCHRONIZATION

a. To improve the resolution of measurement, the oscilloscope sweep must be at as high a rate as possible. The user, instead of depending on the calibrated sweep in the scope, can generate an independent trigger pulse. He then positions the pulse to achieve maximum, practical sweep speed and makes his measurement. Note that the independent trigger pulse can be accomplished by using an oscilloscope with a built-in delayed sweep circuit or with an external trigger generator. The latter method is discussed here:

b. As before, the time of day the measurement is to be made should be established and adhered to for consistent results. Measurements should be made each day within 10 minutes of the designated time. A time of day should be selected when the midpoint of the transmitter-receiver path is near midday. For night measurements, a time should be chosen when the midpoint of the path is near midnight. Measurements should not be made near twilight.

c. The equipment should be connected as shown in figure 8-2. A commercially available frequency divider and clock can be used in place of the controlled delay generator. A time interval counter is then used to measure the output of the delayed clock relative to the master clock. The output of the delayed clock is used to trigger the oscilloscope.

d. The initial procedures described in the direct trigger method also apply to this method and, therefore, should be referred to in setting time with an HF source.

e. With the oscilloscope sweep adjusted to 1 ms/division, the trigger pulse from the delay generator or the delayed clock should be delayed by an amount equal to the propagation delay. Initially, any fractional milliseconds in the delay can be neglected. The sweep should be adjusted so that it begins exactly at the left end of the horizontal graticule and is vertically centered.

f. The second zero crossover point of the tick should be observed and carefully measured. With the sweep at 1 ms/division, the delay of the second zero crossover on the oscilloscope can be measured to the nearest one-tenth of a millisecond and added to the trigger delay resulting in an approximate total time delay. If the local master clock 1 pps time is exactly coincident with the UTC seconds pulse, the total measured time delay will be approximately equal to the sum of the propagation delay time, the receiver delay time and the cycle correction (one period of the tick).

g. To further increase the resolution of delay measurement, the oscilloscope sweep rate can be increased to 0.1 ms/division (100 μs/division) and the trigger pulse from the generator adjusted to be approximately 500 microseconds less than the total delay time previously measured. At these settings, the second zero crossover of the tick will be somewhere near the midscale of the oscilloscope face.

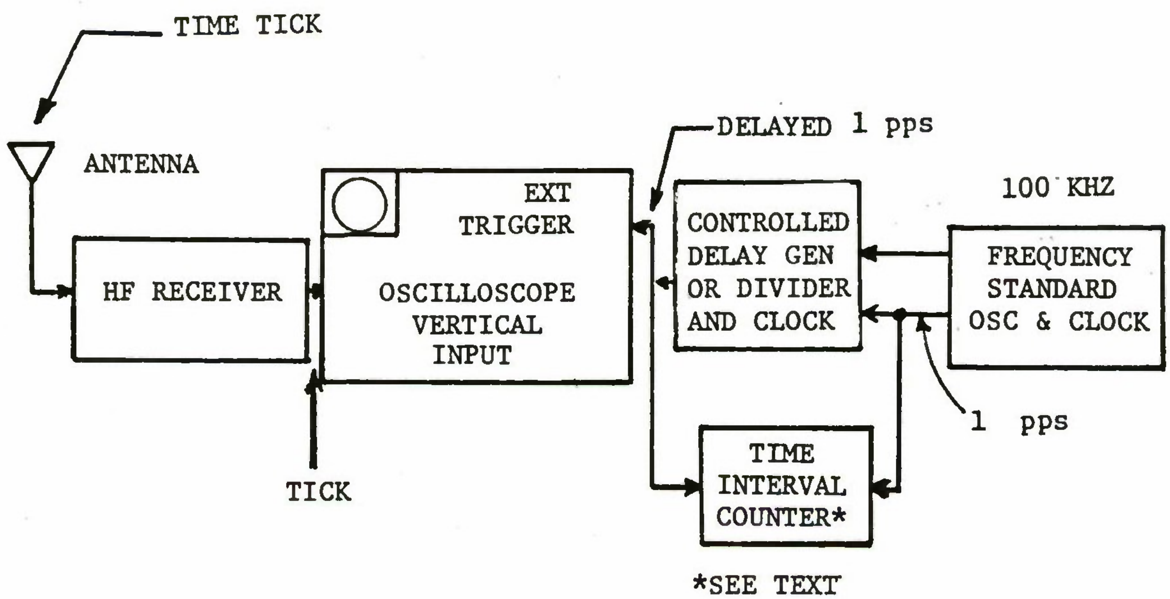


Figure 8-2 Equipment Setup for Delayed Trigger Method of Time Synchronization

h. The vertical centering of the sweep should be rechecked and centered if necessary. The tick is measured to the nearest 10 microseconds. The result should be within ±100 microseconds of the result obtained at the 1 ms/division sweep rate. If the result of this measurement falls outside this tolerance, then the procedure should be repeated by measuring the total time delay at a sweep rate of 1 ms/division.

i. To obtain the time with respect to UTC, the equation given in the direct trigger method, described in 8.1b, should be used.

CHAPTER 9

VERY LOW FREQUENCY

The propagation characteristics of VLF transmissions make them quite useful in certain areas of PTTI.

VLF signals follow the earth's curvature, in effect being guided as though by a duct having the ionosphere as its top surface. Since the ionosphere acts as a boundary rather than as a direct reflector, its variations have a much reduced influence. The high phase stability and long range coverage of the lower frequencies make them valuable for standard frequency transmissions.

Variations in propagation conditions do, however, exist, and for accurate comparison measurements, account must be taken of such variations as those associated with the diurnal shift (phase shifts occurring at sunrise and sunset). Factors affecting path phase velocity include ionospheric conditions, ground conductivity, and surface roughness.

Since the phase velocity of long range VLF signals depends to an extent upon the effective height of the ionosphere, sudden atmospheric disturbances such as those occurring during solar flare events cause sudden phase anomalies. Other changes in VLF propagation are believed to relate to polar cap events, magnetic activity, nuclear explosions, and even meteor showers.

A local frequency standard can be maintained to within a part in 10^{10} or better by comparison of its relative phase to that of a received VLF carrier. Any one of a number of monitoring systems may be chosen to make this comparison possible, depending on the degree of precision required of the relative phase measurement. For the greatest precision, the local standard must have a low drift which is predictable to within a few parts in 10^{10} over several days.

If no better than a part in 10^8 is desired, a nearly instantaneous direct comparison for a short time may be used. If a part in 10^9 is desired, comparison must be continued for long enough to reveal any ionospheric disturbance. While low frequency signals are relatively immune to propagation variations, best results usually are obtained when the total propagation path is in sunlight and conditions are stable. Near sunrise and sunset noticeable shifts both in amplitude and in phase occur.

There are numerous VLF transmitters at worldwide locations whose carrier frequencies are stabilized by cesium oscillators. For details as to location, power, signal format, etc., refer to the latest NAVOBSY Time Series announcement, Series 1.

A simplified block diagram of a VLS receiving/phase comparison system is shown. The system can be as simple as a tuned amplifier utilizing an oscilloscope for a phase comparator, or as complex as a superheterodyne receiver employing digital synthesizers, phase lock loops, phase tracking servos and built-in phase recorders. In any case, the fundamental concept remains the same, i.e., the phase comparison of the local oscillator output with the receiving carrier from stabilized transmitter over a period of time. The results of the measurement are two values (t_1, t_2) of relative phase difference (between the received signal and the local oscillator) taken at the beginning and end of a period of time T. These values translate directly into relative frequency:

$$\frac{t_1 - t_2}{T} = \frac{\Delta t}{T} = \frac{\Delta f}{f}$$

where $\frac{\Delta f}{f}$ is the relative frequency of the local oscillator compared to the received reference frequency. For example, if a phase difference of 1 micro-second was observed over a one-day period:

$$\frac{\Delta f}{f} = \frac{\Delta t}{T} = \frac{1 \text{ microsecond}}{1 \text{ day}} = \frac{1 \times 15^{6}}{86,400}$$

$$= 1.16 \times 10^{-11}$$

When the relative frequency is large, a useable value can be computed using only a few hours of data. If the relative frequency is very small, many days have to be used in the computation. This is especially true when the radio propagation stability is poor or the signal is noisy. If many days are involved

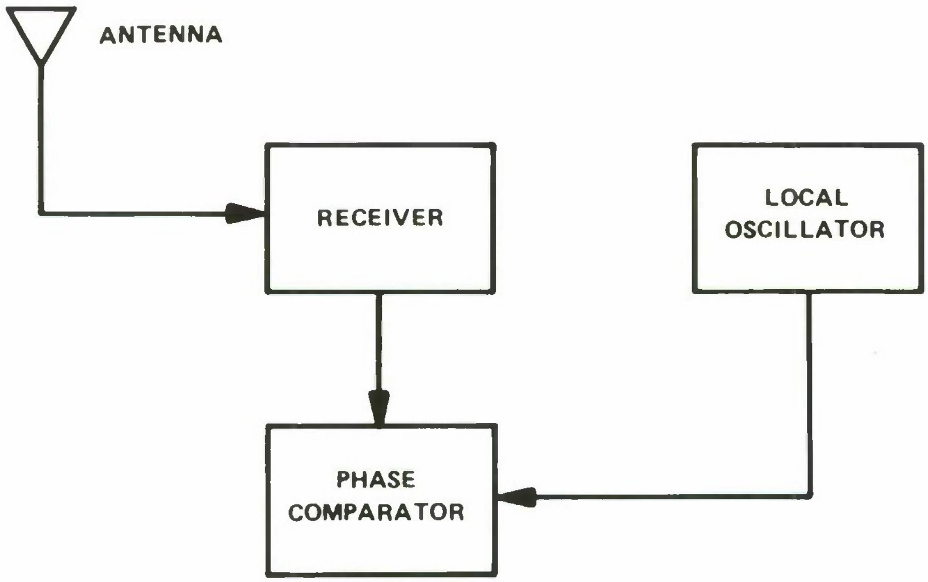


Figure 9-1 VLF Receiver/Comparator

in the measurement, cycle jumps and transmitter phase shifts entered into the phase plot must be carefully taken into account.

U.S. Navy VLF stations are currently transmitting using Multiple Shift Keying (MSK). Reception of the signals requires special equipment. Contact NAVOBSY for details, if required. Daily phase values for selected VLF stations are available via NAVOBSY Time Service Announcement, Series 4 and 5, and by telephone on (202) 254-4662 or Autovon 294-4662.

CHAPTER 10
THE OMEGA SYSTEM

The Omega Navigation System is composed of a group of VLF radio stations operating in the 10 to 15 kHz range. Each station time-shares common frequencies used for navigation. In addition, each station may transmit some frequencies unique to that particular station.

All stations now transmit three basic navigational frequencies (10.2 kHz, 11-1/3 kHz, 13.6 kHz) more or less omnidirectonally. In order to prevent interference, transmissions from each station are time-sequenced as shown in figure 10-1.

This pattern is arranged so that during each transmission interval (approximately 1 second), each station is radiating at a different frequency. The duration of each transmission varies from 0.9 to 1.2 seconds, depending on the station's assigned location within the signal pattern. With eight stations in the implemented system and a silent interval of 0.2 second between each transmission, the entire cycle of the signal pattern repeats every 10 seconds.

The Omega signal format is designed so that each station within the network can be identified by the transmission of a particular frequency at a prescribed time. In addition, the synchronization of all transmissions is tightly controlled, and the phase relationships between all signals are maintained to within a few centicycles. With this high phase stability in the transmissions, the accuracy of a navigational fix is then primarily limited to the receiver and the accuracy of the navigator's propagation correction tables.

All Omega transmitting stations are synchronized by means of very stable cesium beam frequency standards. These standards or clocks are reference to the atomic time scale, which differs from Coordinated Universal Time (UTC) more commonly in use. Thus, in 1980, the Omega epoch or time reference is 9 seconds ahead of UTC since the yearly adjustments for earth motion have not been made to make Omega Epoch in agreement with UTC.

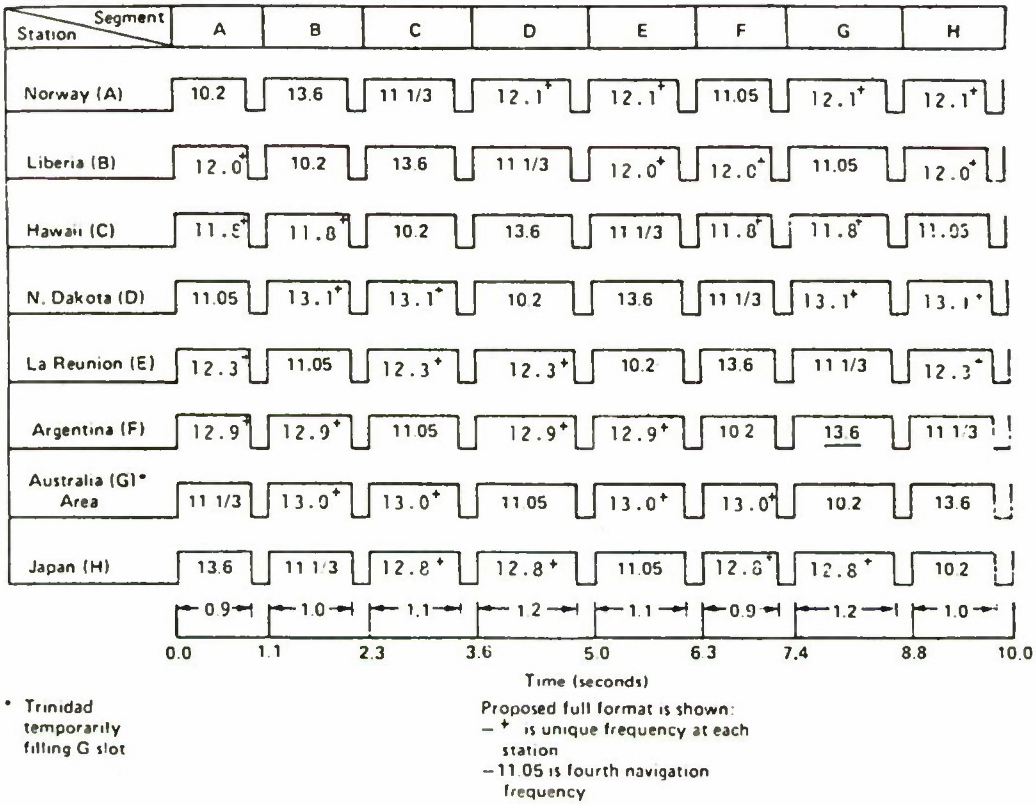


Figure 10-1 Omega Signal Transmission Format

If one wishes to use an Omega station for frequency calibration, a phase-tracking receiver is highly recommended. If one of the navigation frequencies is to be used, then an Omega commutator must also be used. This is a device that turns the phase-tracking receiver on and off at the proper times to receive only the desired Omega station.

The frequencies and the format segments of the Omega stations are derived from cesium beam oscillators. The USNO monitors and reports the Omega stations' phase values. These stations radiate a nominal 10 kW of power. This power level should be sufficient to allow the user to receive at least three stations no matter where he is located.

Data recovered from Omega transmissions are treated the same as other VLF transmissions. Daily phase values for Omega are published by the NAVOBSY in Time Service Announcements, Series 4 and 5, and are available via telephone on (202) 254-4662 and Autovon 294-4662.

CHAPTER 11

SATELLITE COMMUNICATIONS (SATCOM) TIME TRANSFER

The NAVOBSY responsibility to maintain precise time coordination on a worldwide basis requires frequent comparisons of distant time standards with traceability to the NAVOBSY DoD Master Clock. The use of communications satellites to perform these long-distance comparisons (time transfers) has proven highly effective. Accuracies on the order of 0.1 microsecond between stations are routinely achieved. This operational system has DoD controlled, precise reference clocks at satellite communications (SATCOM) terminals in key areas throughout the world.

11.1 SYSTEM CONFIGURATION AND OPERATIONAL DIRECTIVES

The message that follows was sent from the Defense Communications Agency (DCA) (071833Z February 1979) to all commands involved. It formalized the structure of the Defense Satellite Communications Systems (DSCS) for PTTI. Figure 11-1 is a graphic presentation of the message content and includes additional information on clocks at each station and on PTTI monitoring and dissemination capabilities.

A second message from DCA (131853Z June 1979) provided operational guidelines for the PTTI mission and established the operating procedures and system parameters required for successful PTTI operations. These, combined with the DoD directive, are the basis for the present NAVOBSY/SATCOM PTTI activities.

11.1.1 DSCS Message

DTG 071833Z FEBRUARY 1979

DCA WASH DC
DCA EUR VAIHINGEN GE //E570//
DCA PAC WHEELER AFB HI //P518//
USACC ECTC FT DETRICK MD //CCNKE-OPN/CCKNE-SAT-FD//
CDR USACC SATCOMSTA CAMP ROBERTS CA //CCNKR//
CDR 1961 CG CLARK AB PI //LGME//

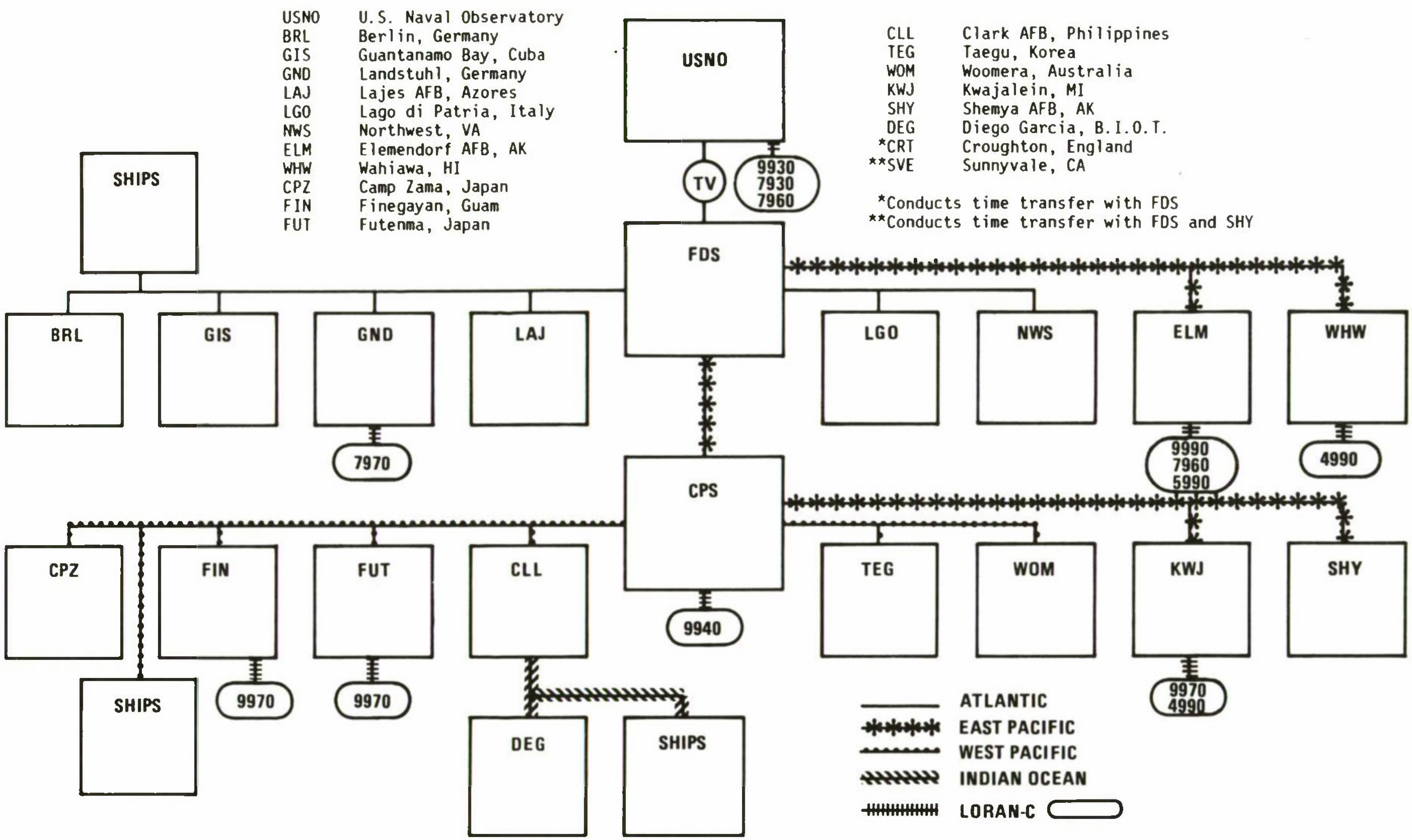


Figure 11-1 SATCOM Time Transfer System

INFO NAVOBSY WASH DC
USACC SATELLITE STA LAKEHURST NJ //ACCNH/OP//
CDR SATCOM STATION LANDSTUHL GE //CCE/X/K/LSL//
COMNAVTELCOM WASH DC
USCOB BERLIN GE //AEBUGE//
CDR 1956CG OLC CAMP ZAMA JA
NAVCOMSTA DIEGO GARCIA
1931CG ELMENDORF AFB AK //LGMI//
NAVCAMS WESTPAC GUAM
NAVSATCOMMDET GUANTANAMO BAY CUBA
NAVCAMS EASTPAC HONOLULU HI //N02053//
CDR 169TH SIG CO TAEGU KOREA //CLK-SBT-B-SAT//
NAVSATCOMFAC NORTHWEST VA //N02050//
1936CG LAJES FLD AZORES //LGMI//
NAVCAMS MED NAPLES IT //N02060//
CDR DCS STA KWAJALAIN MI //FSC-78//
HQ AFCS SCOTT AFB IL
USACC FT HUACHUCA AZ
USASIG SCHOOL FT GORDON GA
DCEC RESTON //R430//
USASATCOMA FT MONMOUTH NJ
DET 6 1957CG WOOMERA AS //LGM//
CDR USACCJSAS FT BUCKNER JP //DSCS TERMINAL//

UNCLAS
DCA 515/
SUBJ: PRECISE TIME AND TIME INTERVAL VIA THE DEFENSE SATELLITE COMMUNICATIONS SYSTEM

1. THE PURPOSE OF THIS MESSAGE IS TO DESIGNATE THE MASTER TIME REFERENCE STATION FOR THE DEFENSE SATELLITE COMMUNICATIONS SYSTEM (DSCS) AND OUTLINE A WORLDWIDE CONFIGURATION FOR IMPLEMENTING THE TRANSFER OF PRECISE TIME AND TIME INTERVAL (PTTI) VIA THE DSCS.

2. FT DETRICK IS HEREBY DESIGNATED THE MASTER TIME REFERENCE STATION FOR THE DSCS.

3. THE FT DETRICK ATOMIC STANDARDS WILL BE MAINTAINED IN CLOSE SYNCHRONIZATION WITH THE U.S. NAVAL OBSERVATORY MASTER CLOCK IN ACCORDANCE WITH NAVAL OBSERVATORY

INSTRUCTIONS. FT. DETRICK WILL, IN TURN, TRANSFER PTTI DIRECTLY TO ALL PARTICIPATING DSCS STATIONS AND U.S. NAVY SHIPS VIA THE ATLANTIC AND EAST PACIFIC SATELLITES (EXCLUDING KWAJALEIN).

4. CAMP ROBERTS, UPON ESTABLISHING PTTI REFERENCE WITH FT DETRICK VIA THE EAST PAC SATELLITE, WILL TRANSFER PTTI TO KWAJALEIN VIA THE EAST PAC SATELLITE USING THE NAVAL OBSERVATORY TIME TRANSFER MODEM. IN ADDITION, CAMP ROBERTS WILL TRANSFER PTTI DIRECTLY TO ALL PARTICIPATING DSCS STATIONS AND U.S. NAVY SHIPS ACCESSING THE WEST PAC SATELLITE.

5. CLARK AB, AFTER ESTABLISHING PTTI REFERENCE WITH CAMP ROBERTS VIA THE WEST PAC SATELLITE, WILL TRANSFER PTTI TO ALL PARTICIPATING STATIONS AND U.S. NAVY SHIPS ACCESSING THE INDIAN OCEAN SATELLITE.

6. PARTICIPATING STATIONS ARE CONSIDERED TO BE DSCS STATIONS AND CERTAIN U.S. NAVY SHIPS EQUIPPED WITH ATOMIC CLOCKS AND SPREAD SPECTRUM MODEMS OR ATOMIC CLOCKS AND TIME TRANSFER MODEMS. STATIONS PRESENTLY EQUIPPED ARE:

ATLANTIC - LANDSTUHL GE, BERLIN GE, NORTHWEST VA, GUANTANAMO BAY CU, LAGO DI PATRIA IT, LAJES AZ, FT DETRICK MD.

EAST PACIFIC - WAHIAWA HI, ELMENDORF AK, CAMP ROBERTS CA, KWAJALEIN MI.

WEST PACIFIC - CLARK AB PI, FINGAYAN GU, TAEGU KA, CAMP ZAMA JA, WOOMERA AS, FT BUCKNER OKIN.

INDIAN OCEAN - CLARK AB PI, DIEGO GARCIA.

7. PTTI REPORTING WILL CONTINUE IN ACCORDANCE WITH EXISTING PROCEDURES.

8. REQUEST CDA AREA SATELLITE OFFICES SCHEDULE PTTI ACTIVITIES IN SUPPORT OF THIS REQUIREMENT.

11.1.2 Operational Guidelines Message

R 131853Z JUN 79
FM DCA WASH DC
TO RUFTDCA/DCA EUR VAIHINGEN GE //E570//
RUHHAAA/DCA PAC WHEELER AFB HI //P518//
RUEOAHA/USACC ECTC FT DETRICK MD //CCNKE-OPN/CCKNE-SAT-FD//
RUWMAWA/CDR USACC SATCOMSTA CAMP ROBERTS CA //CCNKR//
RHMTAAA/CDR 1961 CG CLARK AB PI //LGME//
RUFTTLA/CDR SATCOM STATION LANDSTUHL GE //CCE/X/K/LSL//
RUDOFVA/USCOB BERLIN GE //AERUGE//
RUADJHA/CDR 1956 CG OLC CAMP ZAMA JA

RUVNSAA/NAVCOMSTA DIEGO GARCIA

RUWMBKA/1931 CG ELMENDORF AFB AK //LGMI//

RUHGSAA/NAVCAMS WESTPACK GUAM

RUEBAHA/NAVSATCOMMDET GUANTANAMO BAY CUBA

RUHPSAA/NAVCAMS EASTPACK HONOLULU HI //N02053//

RUAKRFA/CDR 169TH SIG CO TAEGU KOREA //CLK-SBT-B-SAT//

RUWMEHA/CDR 2064 CS SHEMYA AFB AK //LGMS//

RULYWCB/NAVSATCOMFAC NORTHWEST VA //N02050//

RUDLAAA/1936 CG LAJES FLD AZORES //LGMT//

RUFRSAA/NAVCAMS MED NAPLES IT //N02060//

RUHHBAA/CDR DCS STA KWAJALAIN MI //FSC-78//

RUWMABA/DET 6 1957 CG WOOMERA AS //LGM//

RUADBEM/CDR USACCJSAS FT BUCKNER JP //DSCS TERMINAL//

INFO RULSSDA/COMNAVTELCOM WASH DC-

RUCLEWA/HO AFCS SCOTT AFB IL-

RUWJHRA/USACC FT HUACHUCA AZ-

RUCLDIA/USA SIG SCHOOL FT GORDON GA-

RUEADCA/DCEC RESTON VA //R430//-

RUEDBIA/USASATCOMA FT MONMOUTH NJ-

RUEDBIA/CDR USACSA FT MONMOUTH NJ //CCM-TS-A//-

RUEOPAK/NAVOBSY WASH DC

BT

UNCLAS

DCA 515/

SUBJ: COORDINATION OF REDUNDANT CESIUM CLOCKS WITH UNIVERSAL TIME

COORDINATED (UTC)

A. DEFENSE COMMUNICATIONS ENGINEERING CENTER TECHNICAL REPORT NO. 23-77.
DCS II TIMING SUBSYSTEM

B. JCS MASTER NAVIGATION PLAN SM-217-71, ANNEX C. PTTI, 7 APRIL 71

C. MJCS 88-76, 17 MAR 76, "TRANSFER OF PRECISE TIME AND TIME INTERVAL BY THE DEFENSE SATELLITE COMMUNICATIONS SYSTEM"

D. DOD DIRECTIVE 5160.51

1. THE PURPOSE OF THIS MESSAGE IS TO ESTABLISH A PROCEDURE WHEREBY REDUNDANT CESIUM CLOCKS MAY BE SYNCHRONIZED WITH UNIVERSAL TIME COORDINATED (UTC).

2. THE DSCS EARTH TERMINALS ARE EQUIPPED WITH CESIUM CLOCKS TO PROVIDE PRECISE TIME AND FREQUENCY TO ENABLE RAPID ACQUISITION AND MAINTENANCE OF SYNCHRONIZATION BETWEEN SPREAD SPECTRUM MODEMS UNDER STRESSED CONDITIONS, IN ADDITION TO SYNCHRONIZING SPREAD SPECTRUM EQUIPMENT, THIS PRECISE TIME CAPABILITY IS USED TO MONITOR AND COORDINATE OTHER PTTI SYSTEMS, SUCH AS LORAN-C CHAINS. IN TURN, OTHER COMMUNICATIONS SYSTEMS USE LORAN-C TO SYNCHRONIZE THEIR CLOCKS (E.G., AUTODIN, DCS CHANNEL PACKING EQUIMENT, ETC.); SEE REF A. THE MUTUAL DEPENDENCE OF THESE AND OTHER TIMING/NAVIGATION SYSTEMS IS OUTLINED IN REF B.

3. MULTIPLE CESIUM CLOCKS ARE INCLUDED IN MOST EARTH TERMINALS FOR REDUNDANCY. IN ORDER TO ASSURE RAPID ACQUISITION OF THE SPREAD SPECTRUM SIGNALS, THE CLOCK AT THE RECEIVING TERMINAL MUST BE COORDINATED TO WITHIN 10 MICROSECONDS OF THE CLOCK AT THE TRANSMITTING TERMINAL. THIS CAN BE ACCOMPLISHED FOR ALL PAIRS OF TERMINALS WITHIN THE NETWORK IF EACH CLOCK IS COORDINATED TO WITHIN 5 MICROSECONDS OF UTC AS DETERMINED BY THE U.S. NAVAL OBSERVATORY (NAVOBSY). REFS C AND D PROVIDE FOR THE USE OF THE DSCS FOR TRANSFERRING PRECISE TIME AND TIME INTERVAL TO ALL DSCS TERMINALS EQUIPPED WITH THE AN/URC-55, AN/URC-61, AN/USC-23, OR THE OM-55 SPREAD SPECTRUM EQUIPMENT OR WITH TIME TRANSFER MODEMS.

4. UP TO NOW, NO DEFINITIVE TOLERANCE HAD BEEN ESTABLISHED FOR THE ACCURACY TO BE MAINTAINED BY THE EARTH TERMINAL CLOCK. FURTHER, THE MULTIPLE CLOCKS AT ONE LOCATION WERE NOT REQUIRED TO BE COORDINATED WITH ONE ANOTHER, AND ONLY ONE OF THESE CLOCKS AT A LOCATION IS COORDINATED WITH UTC (NAVOBSY). THIS PREVENTED THE REDUNDANT CLOCKS FROM BEING FULLY EFFECTIVE IN PROVIDING THE DESIRED BACKUP TO THE PRIMARY CLOCK. SINCE THERE ARE TYPICALLY FOUR CLOCKS AT EACH LOCATION AND IN ONE EXTREME CASE AS MANY AS EIGHT, THIS LACK OF COORDINATION AMONG THE CO-LOCATED CLOCKS CAUSED CONSIDERABLE CONFUSION AND LOSS OF THE POTENTIAL CAPABILITY MADE AVAILABLE BY HAVING THE REDUNDANT CLOCKS.

5. TO RESOLVE THESE PROBLEMS, A TOLERANCE HAS NOW BEEN ESTABLISHED FOR THE TIME ACCURACY OF ALL CLOCKS IN THE DSCS, AND THE PRECISION OF THE MEASUREMENTS BY WHICH THIS TOLERANCE IS TO BE MAINTAINED.

A. EACH STATION EQUIPPED WITH CESIUM CLOCKS AND THE MEANS TO PERFORM PTTI WILL MAKE THE NECESSARY TIME TRANSFER MEASUREMENTS AND IMPLEMENT THE NECESSARY CLOCK CORRECTIONS AS DETERMINED BY THE NAVOBSY TO ASSURE THAT EACH CLOCK IS MAINTAINED WITHIN PLUS OR MINUS 5 MICROSECONDS OF UTC (NAVOBSY) WITH A MEASUREMENT PRECISION BETTER THAN 0.1 MICROSECOND.

B. NO CLOCK ADJUSTMENTS ARE TO BE MADE WITHOUT SPECIFIC INSTRUCTIONS FROM NAVOBSY.

C. THE COORDINATION OF ALL REDUNDANT CLOCKS AT THE EARTH TERMINAL CAN BEST BE ACCOMPLISHED BY PERIODICALLY MEASURING THE TIME DIFFERENCE BETWEEN EACH OF THE REDUNDANT CLOCKS AND THE PRIMARY CLOCK, INFORMING THE NAVOBSY OF THESE TIME DIFFERENCES, AND MAKING THE CLOCK CORRECTIONS IN RESPONSE TO SPECIFIC DIRECTIONS FROM THE NAVOBSY.

D. EACH DSCS TERMINAL SO EQUIPPED WILL: (1) IDENTIFY THE STATION PRIMARY CLOCK TO THE NAVOBSY BY SERIAL NUMBER; (2) COMPARE REDUNDANT CLOCKS TO THE STATION PRIMARY CLOCK AND RECORD DATA DAILY; (3) REPORT DATA TO THE NAVOBSY WEEKLY AS PART OF THE EXISTING REPORTING PROCEDURE (SELECTED EARTH TERMINALS MAY BE REQUIRED TO REPORT DATA MORE FREQUENTLY AT THE REQUEST OF THE NAVOBSY).

E. THE RECOMMENDED MEASUREMENT CONFIGURATION IS ILLUSTRATED IN NAVOBSY TS/PTTI-01M, APPENDIX K (AVAILABLE FROM NAVOBSY UPON REQUEST). THE STATION PRIMARY CLOCK WILL PROVIDE THE START 1 PPS AND THE REDUNDANT CLOCK WILL PROVIDE THE STOP 1 PPS. MEASUREMENT SHOULD BE MADE TO THE BEST ACCURACY ACHIEVABLE WITH INSTRUMENTATION AVAILABLE TO THE TERMINAL.

F. SPECIFIC TECHNICAL QUESTIONS DEALING WITH PTTI EQUIPMENT PROBLEMS MAY BE RESOLVED BY CALLING MR. K. PUTKOVICH, NAVOBSY AV 294-4554, OR BY MESSAGE REQUEST. ALL QUESTIONS PERTAINING TO DATA AND REPORTING CAN BE RESOLVED BY CALLING L. G. FISHER,* NAVOBSY AV 294-4555.

6. REDUNDANT CLOCK COMPARISONS AND REPORTING WILL BEGIN UPON RECEIPT OF THIS INSTRUCTION.

BT

#7660

R 00576/13/JUN2143Z/ACK 086

11.2 TIME TRANSFER TECHNIQUES

The URC-55/61 communications modem time transfer technique requires each station to transmit a pulse and to receive a pulse from another station. At each station, the transmitted and received pulses are compared with the local clock. If half the sum of the two measurements at one station is subtracted from half the sum of the two measurements at the other station, the difference is the time difference between the station clocks (figure 11-2). This relation

*Current point of contact is Ms L. G. Charron.

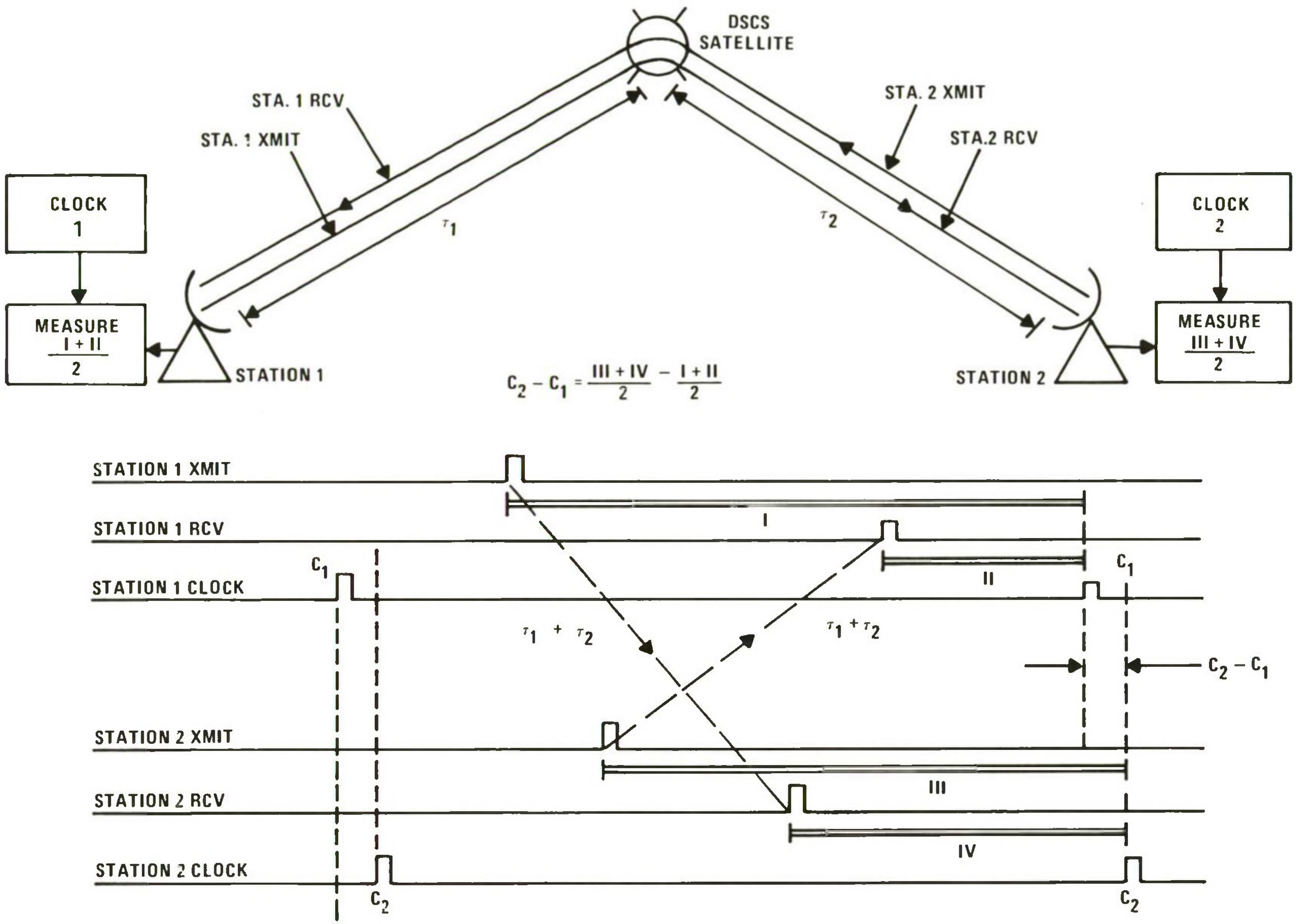


Figure 11-2 Time Transfer Timing Diagram

is valid if the propagation time $\tau_1 + \tau_2$ in one direction is equal to the propagation time in the reverse direction. When using the slow-moving or stationary DSCS satellites, the inaccuracy is less than 0.1 microsecond if the two transmitted pulses occur within one second of each other.

The time transfer unit automatically measures the transmitted and received pulses with the station clock at each station, and generates a burst of pulses equal to half the sum of the two measurements. This burst is totaled and displayed on an electronic counter, or the built-in display on later model units.

A Time Transfer Modem, which employs a code polarity inversion technique, has been developed. The time transfer occurs on a simultaneous command of an initiating pulse at each station. These initiating pulses must be made within one second of each other for the same reason described in the time transfer technique above. Matching the codes is a narrow-band process that can be accomplished in the presence of large amounts of uncorrelated noise, and the modem may be operated at a level considerably below other signals occupying the same channel. The system also requires the time transfer unit for recording the time difference measurements. Figure 11-3 is a functional block diagram for the URC-61 and URC-55. The URC-55 (LTTC) has the counter and time transfer units incorporated into the URC-55 timing central.

11.3 INTERFACE EQUIPMENT

At each SATCOM terminal, a cesium clock, a time transfer unit (TTU), and a time interval counter are used. Later models of the TTU are equipped with a built-in time interval display. Latest versions of the URC-55 incorporate TTU and counter functions in the Link Terminal Timing Central (LTTC).

The TTU and time interval counter interface with the cesium clock and the communication or time transfer modem and operate automatically to yield a single reading at each station. The difference between readings is the time difference between the station clocks. It is necessary for the stations to exchange readings to determine the clock difference. This is accomplished via any communication link between stations.

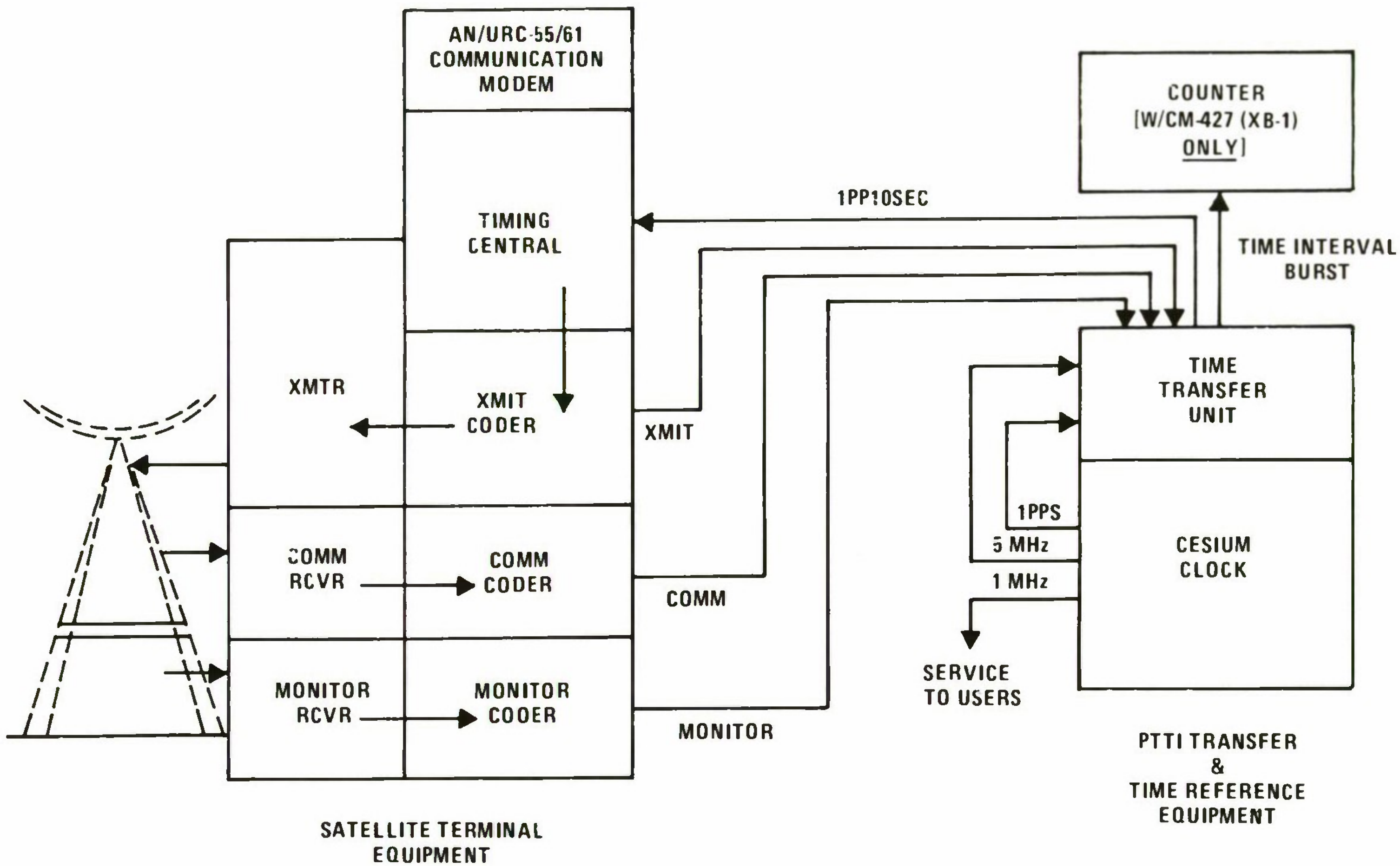


Figure 11-3 Functional Block Diagram of Satellite PTTI Transfer

The NAVOBSY considers the clock difference valid only when the modems of the two stations have made a TTU Start, an easily accomplished procedure when the time difference of the station clocks is less than 50 microseconds.

Although provisions have been made in the TTU for making TTU Starts with the accurate clocks of the time transfer system, a Reset Start may be made when a station has a large, unknown clock error. In this case, the clock may be calibrated by a reference station by using the procedures in 11.5.

Differential time delays between transmitting and receiving terminal equipment produce small fixed time offsets. The individual contributions of the various station components are complicated by frequency conversions that make them very difficult to analyze. It is expected that the effects of the differential delays will prove to be less than 0.1 μsec.

11.4 TIME TRANSFER MODEM

The Time Transfer Modem (TTM) is intended for use at terminals not equipped with pseudorandom code communication modems. These modems produce their own pseudorandom code and, when operating at 10 MHz, the complete code cycle is 819 microseconds. The "all-ones" event recurs once each 819 microseconds, and other information must be transmitted to identify which "all-ones" event is the intended time tick. This is accomplished by the transmitting station initiating a pulse that reverses the phase of the code throughout the next code cycle. The "all-ones" event that terminates that cycle is the designated tick. Similarly, the "all-ones" event that occurs at the end of the phase reversal at the receiving station is recognized as the tick. A block diagram of the TTM configuration is given in figure 11-4.

As the TTM is employed at only a few terminals, operating procedures are not included in this manual and are provided only as necessary.

11.5 CLOCK CALIBRATION AND PTTI TRANSFERS

Time transfers between SATCOM terminals made via the DSCS measure time differences of <u>less</u> <u>than</u> <u>one</u> <u>second</u> <u>only</u>. Any time difference greater than

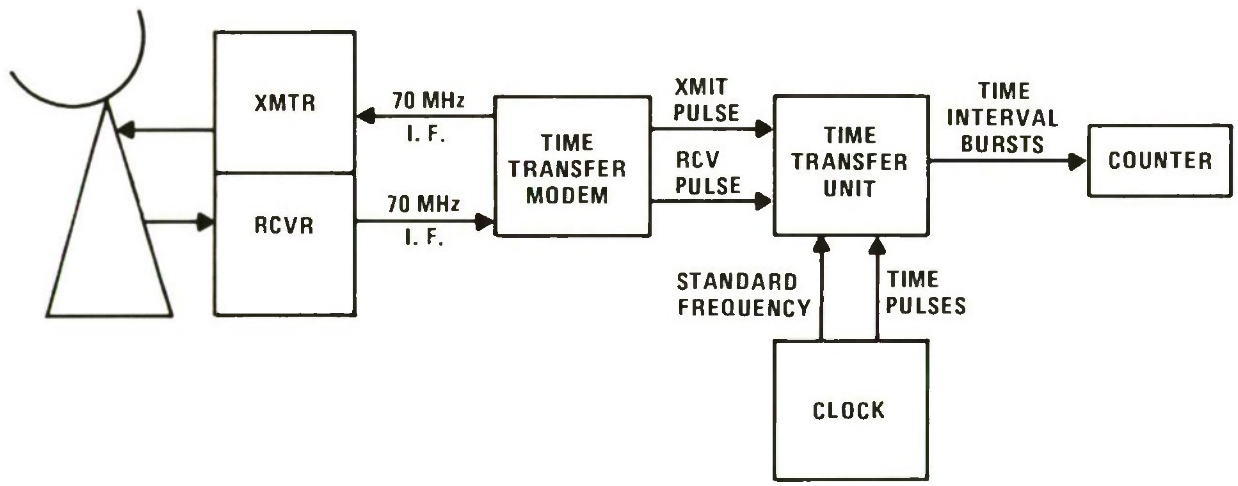


Figure 11-4 Configuration for Time Transfer with Time Transfer Modem

one second must be determined by other means, i.e., WWV, Navy VLF, Autovon or commercial telephone, SATCOM voice circuits, etc. A time difference large enough to preclude a TTU Start with the URC-55/61 modems is unacceptable, and the error must be identified and corrected as soon as possible. Data obtained by the TTU Start procedure only will be reported to NAVOBSY for processing.

Any interruption of a cesium clock operation will introduce an unknown error large enough to require a time calibration of the unit. Malfunctioning units must be restored to an acceptable operating condition before obtaining a time calibration. Any SATCOM cesium clock with an unknown error can be calibrated to another SATCOM reference clock via the DSCS by using the following procedures. (Both stations must be equipped with a time transfer system.) These instructions apply to the URC-61, the URC-55, and URC-55 with the LTTC.

Step 1 Establish voice communications, by any means possible, with a reference SATCOM station that has a calibrated cesium clock traceable to the NAVOBSY and request a time calibration.

Step 2 Synchronize the reference station URC Timing Central clock with the reference station cesium clock as follows:

a. Connect the TTU rear panel +2.5 V pulse to the URC front panel as follows:

1. The START +2.5V output to URC-61 EXT CLOCK START input jack, or
2. The START +2.5V output to URC-55 EXT CLOCK START input jack, or
3. Does not apply to URC-55/LTTC.

b. Stop the URC clock as follows:

1. Press the clock STOP button on the first board to the left inside the URC-61 front panel, or
2. Press the STOP CLOCK button on the front panel of the URC-55, or
3. Does not apply to URC-55/LTTC.

c. Set the TTU 1PP10SEC indicator lamp (blue on TTU, LED on LTTC) to light during each second ending in zero, as read from the cesium clock.

d. Set the front panel thumbwheel switches to some HOUR, MINUTE, and SECOND (ending in zero) ahead of the cesium clock by momentarily pressing the 1PP10SEC SYNC button any time the second on the cesium clock ends in zero.

e. Press the ARM START switch on the TTU or LTTC front panel during the 10 second period preceding the selected time as read from the cesium clock or thumbwheel switches.

f. When the cesium clock time coincides with the URC thumbwheel time, the "armed" TTU permits the 1PP10SEC pulse through to the URC clock, which will start with time relative to the cesium clock as follows:

1. The URC-61 Timing Central clock starts approximately 0.5 second early.

2. The URC-55 Timing Central clock starts approximately 0.5 second late.

Step 3 Both stations make a Reset Start as follows:

a. Establish a specific time to commence the Reset Start.

b. Press the Reset button on the XMIT, COMM, and MONITOR units.

c. When the sync lamp (blue) lights on the COMM and MONITOR units, press the XMIT WIDEBAND button. (When the WIDEBAND button lights, the RESET button lamps will go out.)

d. Set the DATA RATE switch to 4800 on the XMIT, COMM, and MONITOR units.

e. If data synch is not achieved on all receivers, repeat steps 3c and 3d.

Step 4 Set up both stations for synchronization of the uncalibrated station URC clock by the reference station as follows:

a. Establish a specific hour, minute, and second for the synchronization.

b. Dial this time into both stations' URC front panel thumbwheel switches.

c. Place the reference station URC front panel TRANSMIT switch in TRANSMIT.

d. Place the uncalibrated station URC front panel RECEIVE switch in RECEIVE at 30 to 45 seconds before the designated time.

e. At the designated time, the RECEIVE URC clock will synchronize with:

1. A TRANSMIT URC-61 clock at approximately 0.5 second early to the TRANSMIT station cesium clock.

2. A TRANSMIT URC-55 clock at approximately 0.5 second late to the TRANSMIT station cesium clock.

3. A TRANSMIT URC-55 (LTTC) on time with the TRANSMIT station cesium clock.

f. Return the TRANSMIT and RECEIVE switches to the OFF position.

Step 5 Set up both stations and perform a Tick Start (using the URC clocks) as follows:

a. Remove external synch as follows:

1. Place URC-61 front panel clock switch in the INT position, or

2. Remove the TTU 1PP10SEC input from the LCC board inside the front panel of URC-55 timing central, or

3. Go to step 5b if using URC-55 (LTTC).

b. Set the XMIT, COMM, and MONITOR units controls to:

1. DIGITAL
2. 1 CHANNEL
3. DEVIATION 2
4. DATA RATE 4800

c. Set XMIT coder switch to WIDEBAND (transmission in NARROWBAND constitutes a security violation).

d. Determine the current range and doppler data by use of:

1. The prediction tables
2. The TTU as follows:
   a) Place the function switch in TAU position.
   b) Press the RESET button.
   c) Record the counter reading after the XMIT COMP and RECV COMP lamps light.
   d) Multiply the counter reading by 0.3 km/μsec and subtract 24 km.
3. The range readout on the URC-61 front panel.
4. The URC-55 (LTTC) as follows:
   a) Place the function switch in the RANGE position.
   b) Press the reset switch.
   c) Record the range readout.

e. Set the range as follows:

1. Into high KM thumbwheel switches on URC-61 and URC-55 (set low KM switches), or
2. Into range thumbwheel switches on URC-55 (LTTC).

f. Enter range by:

1. Operating the NEW DATA/OLD DATA switch on the URC-61 or URC-55 to light the right side of the switch.
2. Not applicable to URC-55 (LTTC).

g. Both stations establish a specific hour, minute, and second for the start and dial this time into the URC front panel thumbwheel switches.

h. Place the CALIBRATE switch in the TRANSMIT position.

i. Set arm as follows:

1. For URC-61 and URC-55, press the ARM switches on XMIT, COMM, and MONITOR units.
2. For URC-55 (LTTC), go to the next step.

j. Promptly after the coders start, for URC-61 and URC-55, press the RANGE CORRECT switch; or, for URC-55 (LTTC), press the INITIATE switch. The RANGE CORRECT/INITIATE switch should remain lit for about 30 seconds. Both COMM and MONITOR coders should acquire sync during the next 30 seconds.

k. If synchronization is not achieved within 30 seconds after the RANGE CORRECT/INITIATE lamp goes out, set the search switch of the COMM and MONITOR units that have not achieved sync to the EXTENDED position. Return the switch to normal when sync is acquired.

l. Return the CALIBRATE switch to the OFF position.

m. If synchronization is not achieved, verify time and range and repeat step 5.

NOTE

A Tick Start uses the 1PPS from the URC Timing Central clock. A TTU Start uses the 1PP10SEC from the TTU in lieu of the URC clock pulse. Synchronization verifies the range and time to one second.

<u>Step 6</u> Set the uncalibrated station cesium clock hours, minutes, and seconds to the uncalibrated station URC clock as follows:

a. Set the cesium clock SECOND by visual means as follows:

1. Late less than 1.0 second, if synchronized by a URC-61.
2. Early less than 1.0 second, if synchronized by a URC-55.

<u>Step 7</u> Set both stations' TTU front panel 1PP10SEC indicator lamps (blue on TTU, LED on LTTC) to light during each second ending in zero, as read from the cesium clock.

<u>Step 8</u> The difference between the cesium clocks can be reduced to less than 1.0 microsecond by making a PTTI transfer and removing the measured error from the uncalibrated clock.

a. A PTTI transfer is made using the URC-61 or URC-55 by:

1. Setting the TTU function switch to the COMPOSITE position.
2. Pressing the TTU RESET button.
3. Waiting for the XMIT COMP (green) and RCV COMP (red) lamps to light.
4. Recording and exchanging counter readings.

WARNING

If the stations' TTU XMIT COMP and RCV COMP lamps do not light within one second, the cesium clocks are in error by more than one second. The reference station should call out the seconds from its cesium clock over the voice link, and the uncalibrated station should observe the seconds on its cesium clock and make the necessary corrections.

b. A PTTI transfer is made using the URC-55 (LTTC) by:

1. Setting the function switch to TTU.
2. Pressing the reset switch.
3. Recording and exchanging counter readings.

Step 9 The uncalibrated station will subtract algebraically the uncalibrated reading from the reference reading. The correct sign must be retained with the difference value for use in step 10.

EXAMPLE: a. Uncalibrated Clock Late

167898.7 - Reference reading
-946765.2 - Uncalibrated reading
-778866.5 - Clock difference

b. Uncalibrated Clock Early

946765.2 - Reference reading
-167898.7 - Uncalibrated reading
778866.5 - Clock difference

Step 10 The uncalibrated station will add algebraically the clock difference obtained in step 9 to the 6-digit TIME DELAY thumbwheel setting of its cesium clock. (Round off the clock difference to the nearest microsecond.)

EXAMPLE: a. Uncalibrated Clock Late

825032 - Old thumbwheel settings
-778867 - Clock difference
046165 - New thumbwheel settings

b. Uncalibrated Clock Early

825032 - Old thumbwheel settings
778867 - Clock difference
1603899 - New thumbwheel settings (disregard first digit 1)

WARNING

A change of one second can occur when the thumbwheel switch goes through 000000. Recheck the time to verify the second after changing thumbwheels.

Step 11 Set up both stations and perform a TTU Start using the TTU 1PP10SEC pulse as follows (see step 5 above):

a. Place the URC-61 front panel CLOCK switch in the EXT position.

b. Insert the TTU 1PP10SEC input pin into the test point on the LCC board inside the front panel of the URC-55 Timing Central.

c. Perform steps 5b, c, d, e, and f.

d. TTU Starts are normally attempted on every minute ending in 0 and 5 until synchronization is accomplished.

e. Perform step 7.

f. For URC-61 or URC-55, press the ARM switches on the XMIT, COMM, and MONITOR units. Press the ARM switch on the TTU during the 10 seconds preceding the minute selected for starting. For URC-55 (LTTC), go to the next step.

g. Perform steps 5j and k.

Step 12 Make a series of PTTI transfers (see step 8) and record the counter readings on a Satellite PTTI Transfer Record sheet (form TS-2), shown in figure 15-1. Report the new clock difference to NAVOBSY and include a complete explanation in the Notes of the Message Format section (see chapter 15).

NOTE

The procedure for resetting a clock should be used only in the event of a failure which has caused a large unknown error. Clocks should not be routinely reset, and once synchronized they should be adjusted only by direction from NAVOBSY.

CHAPTER 12

PRECISE TIMING VIA TV TRANSMISSIONS[1]

Since 1965, television transmissions from commerical stations have been used around the world to measure precise time and frequency differences between remote timing centers and to disseminate accurate time and frequency signals traceable to international time standards.

The two basic techniques that are most widely used today are a passive system for differential time transfer and a passive system for real time transfer. In the U.S., these two systems are known as TV Line 10 Precision Time Transfer systems.

The techniques described below can be used worldwide with any TV transmission system. However, the applications discussed are for the National Television Systems Committee (NTSC) CCIR: "M" system presently used in the U.S.

12.1 SOME NTSC FUNDAMENTALS AND DEFINITIONS

In the U. S., commercial TV broadcasts are generated at a rate of 30 pictures, or frames, per second. Each frame is composed of 525 lines, and it takes about 33 millseconds to transmit or reproduce them. To minimize picture flicker, each frame is divided into two groups of horizontal lines, called odd and even fields, that are transmitted so as to interlace each other. This process is called interlaced scanning. In this mode of operation, the end of one field is separated from the start of the other by one half of a horizontal line (31.78 μs). The first ten lines of both fields contain equalizing and vertical pulses used to control the position and motion of the lines. For TV precise time transfer, the sync pulse at the start of horizontal line 10 of the odd field was selected as a TV time marker because it is an easy line to identify.

For precise time applications, the line 10 TV time marker was defined as the 50 percent point on the leading edge of the first H synchronizing pulse following, by 1/2 line (31.78 μs), the least post-equalizing pulse in the vertical

[1]From "Time System Technology Application Note 1," J.D. Lavanceau and L.F. Shepard.

interval, or the H synchronizing pulse at the start of line 10 in fields 1 and 3 of the NTSC format, in accordance with EIA RS 170A, as emitted (figure 12-1).

12.2 PASSIVE TELEVISION SYSTEM FOR DIFFERENTIAL TIME TRANSFER

This method consists of recognizing and identifying a portion of a video transmission as a time marker and of simultaneously measuring its time of arrival at remote locations using precision reference clocks. This technique requires that:

a. Two or more timing stations participate in the time transfer.

b. These timing stations receive the same TV broadcase originating from the same TV antenna.

c. They recognize and identify, as described above, that portion of the video transmission used as a TV time marker.

d. They simultaneously record the times of arrival of the TV time markers as read against their respective station clocks.

e. Participating stations exchange these measurements and keep a chronological log of the time differences.

NOTE

To be able to compare the times of arrival of the same TV time markers, all measurements to be exchanged must be taken simultaneously at each timing station.

Comparisions of successive differential measurements will yield the time divergence (differential rates or frequency differences) between the clocks of the participating station. The actual time differences between these clocks can also be calculated simply by subtracting the differential propagation and equipment delays between the timing stations, if known, from the time differences measured above.

12.2.1 Procedure

To simplify the explanation that follows, a time and frequency comparison between only two stations will be discussed. It should be remembered, however, that any number of timing stations can participate in these transfers, as long as they can receive the same TV broadcase simultaneously, as mentioned above.

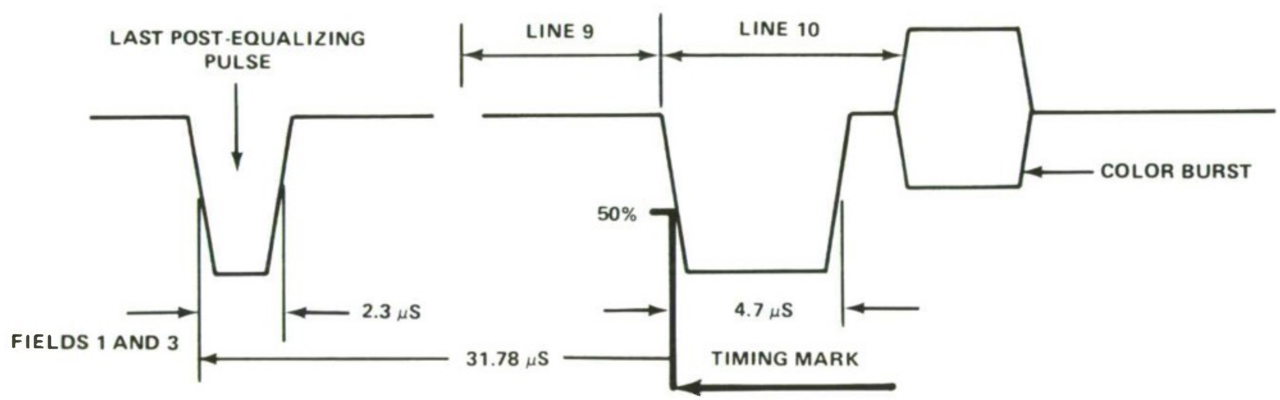


Figure 12-1 Timing Mark Definition

a. Set up the monitoring system as shown on figure 12-2.

b. Tune the TV line 10 discriminationrs of both stations (A and B) to the same TV broadcast or transmitter.

c. At a previously agreed-upon time, start recording the times of arrival of the TV makers, as read on the time interval counters, and the times at which those readings are taken (hours, minutes, and seconds) at both stations A and B. A series of ten to fifteen readings should be sufficient. If time interval printers are not available, measurements can be recorded every 10 seconds instead of every second to facilitate the operation. As can be seen in figure 12-2, each time interval counter is started by the 1 pps from the station clock and is stopped by the next TV time maker generated by the line 10 discriminators from the received TV transmission.

d. Exchange the readings between the stations. Calculate the respective time differences (reading A minus reading B) and record them with the time at which the measurement were taken.

e. Average the time differences to determine the relative difference between the two clock as shown in example 1.

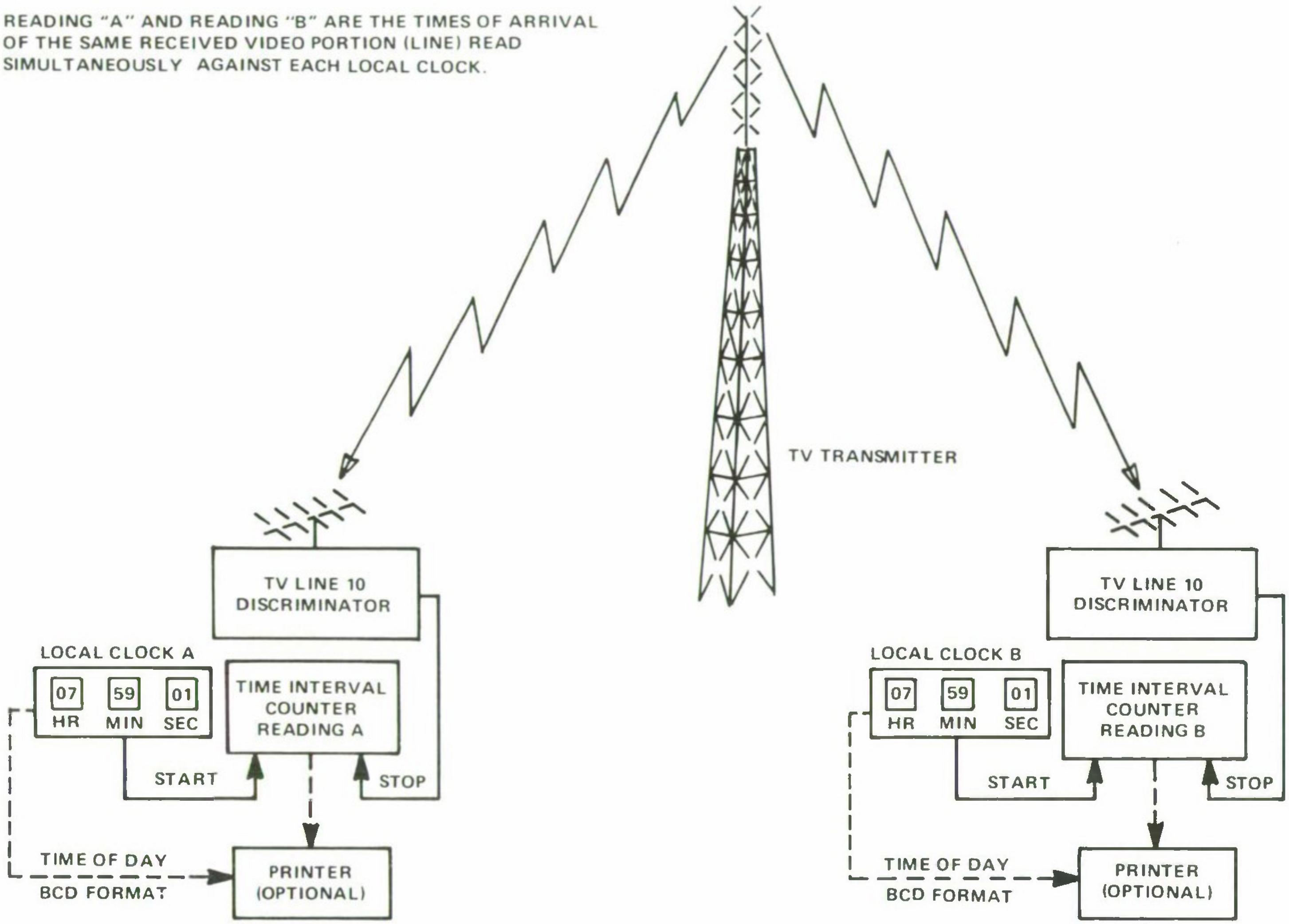
EXAMPLE 1: Assume that, on the 15th of March 1980, the following readings were simultaneously recorded at timing stations A and B.

Times H M S	Reading at A	Readings at B	Differences (Reading A - Reading B)
14 16 30	5921.665 μs	5908.615 μs	13.050 μs
14 16 40	4827.545 μs	4814.420 μs	13.125 μs
14 16 50	3255.985 μs	3242.960 μs	13.025 μs
14 17 00	1637.225 μs	1624.100 μs	12.125 μs
14 17 10	3327.445 μs	3314.400 μs	13.045 μs
14 17 20	3113.555 μs	3100.455 μs	13.100 μs
14 17 30	2432.735 μs	2419.610 μs	13.125 μs
14 17 40	4120.045 μs	4107.005 μs	13.040 μs
14 17 50	5947.185 μs	5934.020 μs	13.165 μs
14 18 00	7673.950 μs	7661.035 μs	12.915 μs
			130.172 μs

From the above, the averaged difference is:

$$\frac{1}{10} \sum_{i=1}^{i=10} (\text{readings } A_i - \text{readings } B_i) = \frac{130.172}{10} \ \mu s = 13.017 \ \mu s$$

NOTE: READING "A" AND READING "B" ARE THE TIMES OF ARRIVAL OF THE SAME RECEIVED VIDEO PORTION (LINE) READ SIMULTANEOUSLY AGAINST EACH LOCAL CLOCK.



(CLOCK A - CLOCK B) = (READING A - READING B) - $(T_a - T_b)$

Figure 12-2 TV Differential Time Transfer Instrumentation System

As stated above, when the difference in propagation and equipment delays (T_a - T_b) between two timing stations is known (this difference can be measured by portable clock or can be computed from the geographical positions of the TV transmitter and TV line 10 discriminator antennas), the actual time difference between the clocks at the timing stations can be calculated as follows:

$$(\text{clock A} - \text{clock B}) = \left[\frac{1}{n} \sum_{i=1}^{i=m} (\text{readings } A_i - \text{readings } B_i) \right] - (T_a - T_b)$$

Where n = number of measurements

For example, assume that from previous measurements the difference in propagation and circuit delays between the two stations and the TV transmitter (T_a - T_b) is 6.6645 μs. The actual time difference between clock A and clock B, then, is:

13.017 μs - 6.645 μs = 6.372 μs

The time divergences (rates or frequency differences) between clock A and clock B can be found simply by comparing successive periodic measurements.

EXAMPLE 2: Assume that the average difference between readings A and reading B, at about the same time daily, is as follows:

17 March 1980	13.070 μs
19 March 1980	13.085 μs
20 March 1980	13.085 μs
21 March 1980	13.080 μs
23 March 1980	13.095 μs
24 March 1980	13.105 μs
26 March 1980	13.110 μs

A plot of these differences (figure 12-3) shows the divergence between the two clocks. The frequency difference between the two clock can be computed from this plot (about 5×10^{-14} for example 2).

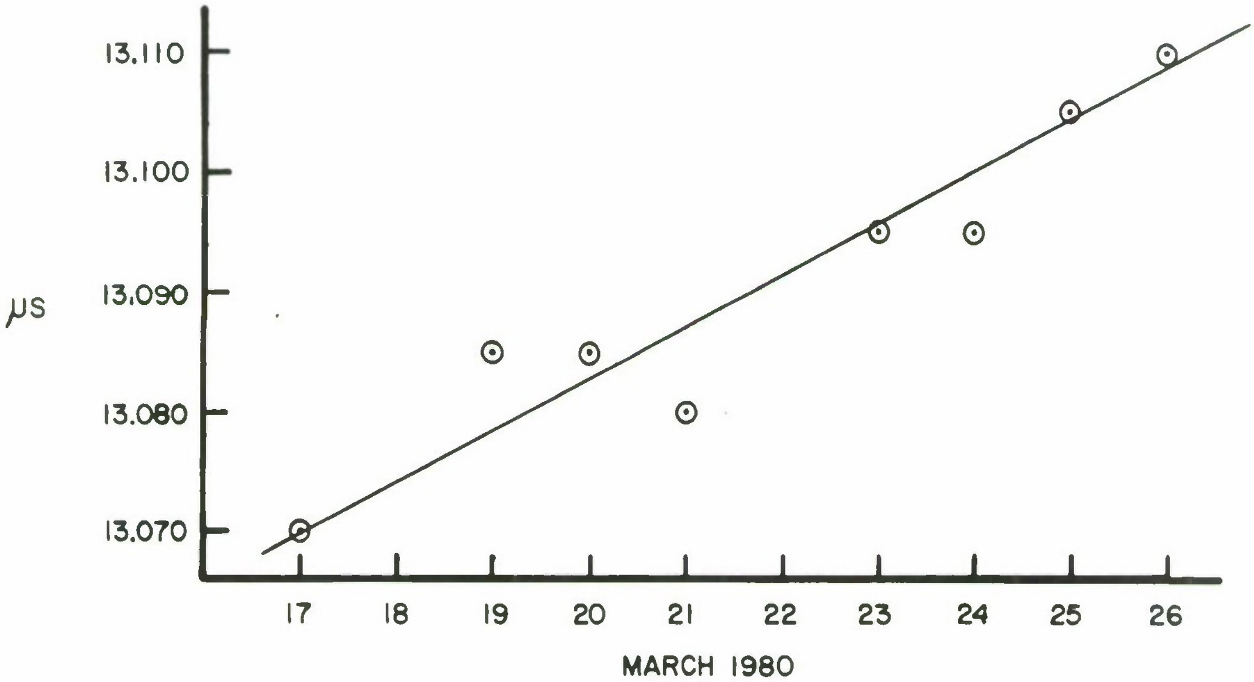


Figure 12-3 Time Divergence Between Station Clocks

12.2.2 TV Frame Ambiguity

For the NTSC system, the time of arrival displayed every second on the time interval counters cannot exceed the period of a TV frame (33.366666 ms). Therefore, if two station clocks are not separated from the television transmission by exactly the same time difference (clock difference plus propagation time delay differences), there may be instances when time of arrival measurements, made simultaneously at each station, will not be made to the same line 10 odd, but to the next or previous one. This TV frame ambiguity, when it occurs, is easily recognized and resolved.

EXAMPLE 3: Assume that the times of arrival of line 10 odd recorded at stations A and B of example 2 above were as follows:

Times H M S	Readings at A	Readings at B	Differences (Reading A - Reading B)
12 11 20	13369.505 μs	13356.500 μs	13.005 μs
12 11 30	23360.650 μs	23356.750 μs	12.900 μs
12 11 40	2.870 μs	33356.375 μs	33353.495 μs
12 11 50	10002.775 μs	9989.700 μs	13.075 μs

The readings taken at time 12 11 40 at stations A and B are the time of arrival measurements made against a different horizontal line 10 odd. This can be verified by adding (or subtracting) the period of one TV frame (33.366666 ms) to the reading taken at 12 11 40, or to the difference formed between readings A and B. The time difference between readings A and B taken at 12 11 40 will then be 13.171 μs, and the averaged difference of all reading will be 13.037 μs. As in the previous example, by subtracting the difference of propagation and circuit delay (T_a - T_b), we obtain the actual time difference between clocks A and B:

(clock A - clock B) = (13.037 μs - 6.6645 μs) = 6.392 μs

12.2.3 Summary

Precise time comparisons or time transfers can be made between time reference stations that simultaneously receive the same TV transmissions. Successive time of arrival measurements of particular horizontal lines (line 10 odd TV time markers) recorded against station clocks will yield a measure of the time divergences (or frequency differences) between these clocks. The actual time differences between these clocks can also be obtained simply by subtracting differential system delays.

For more information and for daily data on network TV differential time transfers, consult USNO Series 4 and NBS Time and Frequency bulletins.

12.3 PASSIVE TELEVISION SYSTEM FOR REAL TIME TRANSFER

This method permits the independent setting of clocks at remote locations to within, in an absolute sense, a few nanoseconds of a reference clock (i.e., (USNO MC). It requires that a TV transmitter be equipped with a reference clock and time control instruments to enable its transmissions to be emitted in synchronization with a reference time scale. This system was developed in 1971 (see references c and d). It has been installed by the U.S. Naval Observatory at television stations in Washington, D.C. (WTTG); Los Angeles, California (KTTV); and Annapolis, Maryland (WAPB). Transmissions from these stations are used routinely by some laboratories in these areas to set their clocks to the USNO MC with accuracies and precisions in the nanosecond region. Any TV transmitter can be set up for this mode of operation.

12.3.1 More NTSC Fundamentals and Definitions

Recurrent waveforms and frequencies of the color subcarrier, the horizontal scan rate, and the vertical frame rate are mathematically related as follows:

The color subcarrier (SC) = 3.579545455 MHz (279.365 ns)

The horizontal scan rate (H) = $\frac{2SC}{455}$ = 15,734.266 Hz (63.555 μs)

The vertical frame rate (V) = $\frac{H}{525}$ = 29.97 Hz (33.366667 ms)

The time period for 30,000 frames is: $30{,}000 \times 33.366667 \text{ ms} \times 10^{-3} = 1001$ seconds exactly.

If an event that occurs at the television frame rate is made to coincide with a 1 pps pulse from a reference clock (i.e., the USNO MC), then another coincidence to another 1 pps pulse from the same clock will occur exactly 1001 seconds later.

By establishing an arbitrary time of coincidence (date) when the first such coincidence occurred, it is possible to calculate the dates (times) at which all subsequent coincidences between the 1 pps output from the reference clock (USNO MC) and the emitted TV line 10 odd horizontal pulses (TV time markers) will occur. These times of coincidence (TOC) have been computed by assuming an initial coincidence at zero hour UT of 1 January 1958 and are published by the USNO as TV TOC tables, time Service Announcement Series 8. (These tables have the same format as those presently used for LORAN-C.)

12.3.2 Operation of TV Real Time Transfer

a. Set up the monitoring system as shown on figure 12-4.

b. Tune the line 10 discriminator to the synchronized transmissions (participating TV transmitter) in your area.

c. Using the USNO TSA Series 8 (TV TOC tables), synchronize the TOC generator to the next time of coincidence.

d. Record the time measurement displayed on the time interval counter. This reading represents the time of arrival of the on-time TV line 10 odd horizontal pulse (TV time marker) emitted by the TV transmitter. This value is the time difference between the monitoring station clock and the TV reference clock (emitted signal), plus the propagation and system delay (C) or:

(local station clock - TV line 10 received) + C

The USNO publishes the daily absolute time corrections to the TV transmissions from WTT (Washington, D.C.), KTTV (Los Angeles, California), and WAPB (Annapolis, Maryland). The actual time difference between a local clock monitoring these transmission and the USNO MC can be obtained as follows:

(USNO MC - local clock) = [(USNO MC - TV emitted)
- (local clock - TV received)] + C

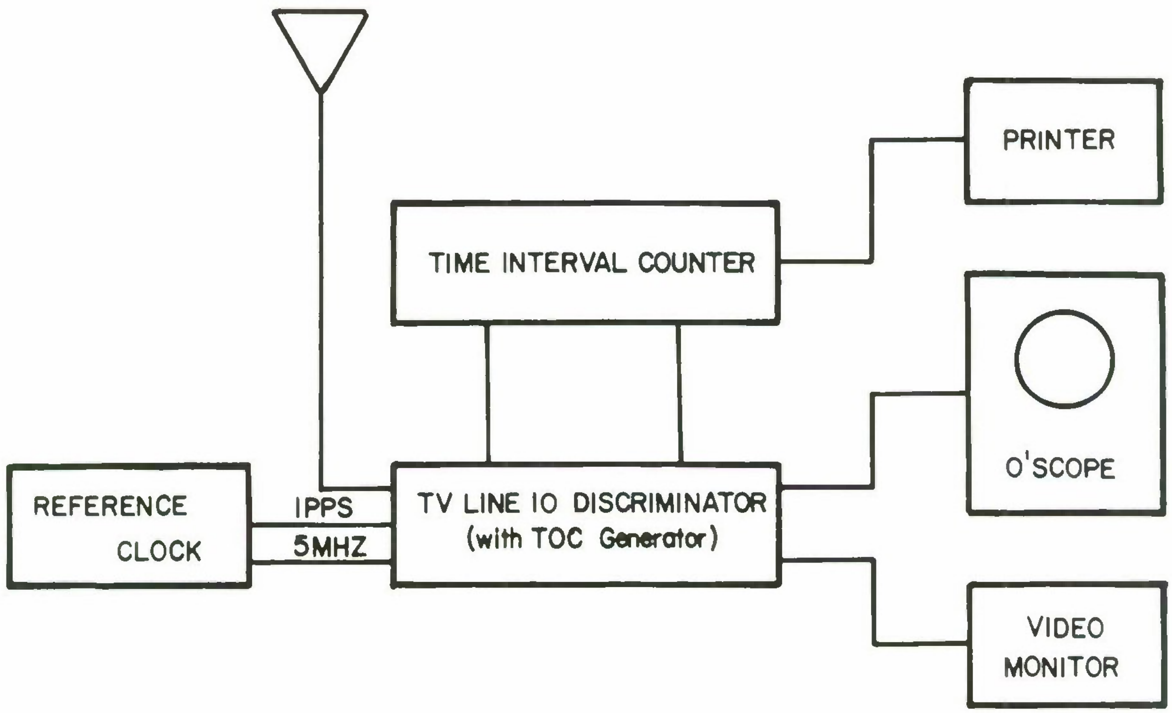


Figure 12-4 Real Time Transfer Instrumentation System

The USNO continuously monitors the transmissions from the TV transmitters mentioned above and keeps them synchronized to the USNO MC by changing, when necessary, the frequency output of the cesium oscillators at the TV transmitters. The daily time differences between the USNO MC and these transmissions are given as corrections on USNO Time Service Announcements, Series 4 and Series 5, by telephone announcements available by dialing (202) 254-4462 or Autovon 294-4662, and by computer via the automated data service on (202) 254-4000 or Autovon 294-4080.

Independent real time comparisons or time transfers, in an absolute sense, can be made by any organization capable of receiving synchronized TV transmissions. Various organizations are presently using this precise time distribution system to set or to compare their clocks to the USNO MC or other reference time standards. These TV time transfers are done routinely to real time accuracies and precisions of ±20 nanoseconds or better.

12.4 REFERENCES

a. "Time Measurements Via Television, Operating Procedure - Instruction Manual for Passive Television System for Differential Time Transfer," Time Service Publication, U.S. Naval Observatory, Washington, D.C. 20390, November 1972.

b. "Timekeeping and Frequency Calibration," Hewlett Packard Application Note 52-2.

c. "Real Time Synchronization via Passive Television Transmissions," Proceedings of the Third Annual DoD Precise Time Interval Strategic Planning Meeting, 16-18 November 1971, held at Naval Research Laboratory, Washington, D.C.

d. "Real Time Distribution via Controlled TV Transmissions," Proceedings of the Ninth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, NASA Technical Memorandum 78104.

e. U.S. Naval Observatory Time Service Announcements, Series 4 and Series 8.

CHAPTER 13

NAVY NAVIGATION SATELLITE SYSTEM (NNSS OR TRANSIT)[1]

The Navy Navigation Satellite System (NNSS or Transit) has been fully operational as a navigation system since 1963. Even though several laboratories have employed special receivers to recover precise time from Transit, there has not been wide recognition and/or use of the unique capabilities of Transit for dissemination of precise time. The polar orbit configuration makes the service available worldwide, and line-of-sight VHF transmission by Transit reduces radio propagation problems associated with other radio-based time systems. Further, since a Fiducial Time Mark (FTM) is transmitted every 2 minutes and this mark is identified in the digital message, it is simple to establish an epoch.

The original navigational design requirement for Transit time was for an accuracy of 500 μs. Operational requirements for this time have not changed, but recent developments (microprocessors) in receiver technology and improvements in spacecraft hardware have increased the usefulness of Transit to the timekeeping community. Time recovery with an accuracy of 10 μs is now available with the current satellite system.

13.1 TIME VIA NNSS

Transit is a system of orbiting satellites and associated ground support developed and maintained for the navigation of ships at sea. The satellite constellation currently contains five satellites in circular polar orbits. It is configured such that, as the earth rotates, a satellite comes into view approximately once each 90 minutes. For navigation, the satellites transmit orbit data defining their position in space and time marks to delimit 2-minute periods over which doppler measurements are made during each satellite pass.

[1]From Navigation: Journal of the Institute of Navigation, Vol 26, No 1, Spring 1979.

Figure 13-1 gives a simplified diagram of the time control circuits in the satellites and the main components of the ground control system. The satellite clock system consists of a stable crystal oscillator and a digital memory driven in such a manner as to give a complete memory readout in exactly 2 minutes. Control of time (or epoch) is provided so that accurate synchronization with the USNO Master Clock (MC) can be maintained.

The satellite transmission contains 6103 bits organized in 156 words of 39 bits each plus 19 additional bits. Of the 39 bits in each word, the first 36 bits contain data while the last 3 bits are for parity, telemetry and clock correction. If the clock correction bit is a zero, the satellite clock does not change. If it is a one, a pulse in the main clock divider chain, equivalent to 48 cycles of the 5 MHz master oscillation, is deleted. This delays all operations in the satellite by $48 \div 5 \times 10^6$ seconds or 9.6 μs, i.e., it lengthens the memory readout by that amount.

A total of 112 time correction bits are available in each message. (The other 44 bits are not used for various reasons.) This permits a control of about one millisecond in the length of the 2-minute interval. The satellite clock is designed to run nominally fast in order to provide positive compensation. Thus, frequency offset and epoch adjustment provide both positive and negative compensation. When the oscillator is at its nominal 4,999,600.00 Hz, 56 time corrections normally are required.

Finer control is provided by time control bits in the ephemeral memory words. These control bits are used only once when a given ephemeral word is read out at word 50. Since they are used only once in a 12-hour memory, these bits have 1/360 the effectiveness of time correction bits in the main memory. With the proper use of all control bits, it is theoretically possible to hold the satellite clock on time within 9.6 μs over a 12-hour memory period.

13.2 SATELLITE TIME CONTROL

The satellite system is under control of the Navy Astronautics Group (NAG). Several ground stations are used to monitor satellite performance and to transmit satellite injection messages. The principle computing facilities and system

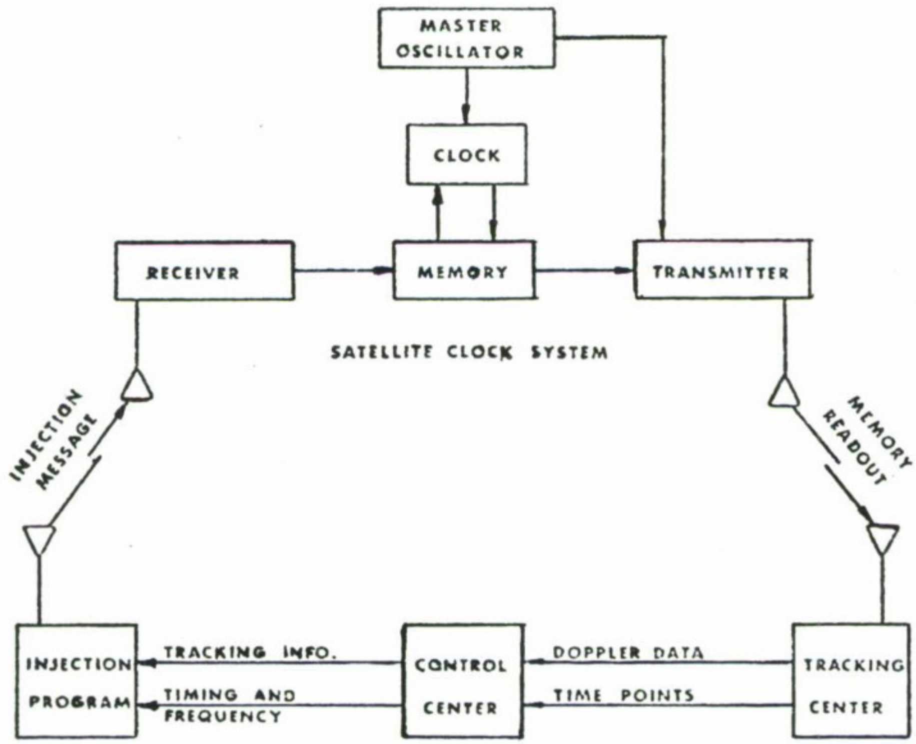


Figure 13-1 Satellite Time Control System

control are at Point Mugu, California. Station clocks are synchronized by portable clock and Loran-C to the USNO MC.

Satellite clock performance is measured relative to the station clock to determine epoch error. Data for each satellite are collected at all stations over a period of about 36 hours to provide clock characteristics that are then used to predict the pattern of time correction bits required to hold the clock on time during the next injection message.

As noted, clock errors are removed in time interval steps of 9.6 μs. The error is non-cumulative, but this does cause a granularity of 9.6 μs in the data which must and can be removed by time recovery receivers. Under current control procedures, the mean value of clock errors is about ±30 μs although individual satellite performance may show a greater error for short periods. Daily values for satellite clock performance are published in the NAVOBSY Time Service Publication, Series 17, "Transit Satellite Report."

13.3 TIME RECOVERY FROM NNSS

Precise time can be recovered from the NNSS transmission with a satellite receiver and a local clock. During each satellite pass, the receiver detects broadcast time marks and decodes the satellite message defining satellite position. The received time marks are compared with the local clock and corrected for transmission delay. Any remaining time difference represents the local clock error. A correction may be applied to the clock to synchronize it with the satellite, or the difference can be noted to represent the epoch error.

The receiver currently available for time recovery from the transit system is microprocessor-based and extremely simple to install and operate. A small (24" x 3" diameter, four-pound) antenna is mounted at least 12 feet from any large objects in an area with as clear a view of the horizon as possible. The receiver can be located up to 100 feet from the antenna. AC power and a 5 MHz reference signal are connected to the receiver. The geographical location of the antenna is entered in the receiver memory via site parameter switches located inside the receiver, and the receiver clock is set to within ±5 minutes of UTC using front panel switches. The next satellite pass will cause the clock and the 1 PPS output to be set on time as determined from data recovered from the satellite. Subsequent satellite passes cause the 1 PPS output to be updated on the basis of each individual pass or on the basis of an average of from 2 to 99 passes. An optional recorder output provides a digital record for each pass and each 1 PPS output update.

13.4 PERFORMANCE OF NNSS TIMING RECEIVERS

Transmission accuracy of the satellite time marks determines the timing accuracy of the system. As noted earlier, present satellite time control procedures maintain individual satellite clocks to within about 30 μs of the USNO MC or UTC, and the mean value of all satellites is normally within 10 μs.

The timing output of the system has been monitored at USNO, and the results for one period are presented in figure 13-2. The points represent the difference between Transit Satellite System Time and USNO MC. Each point contains an average of the satellite passes, thus insuring that several satellites contributed to the resulting time scale. It can be seen that the deviation from USNO MC is small.

REFERENCE

Hunt, G. A. and R. E. Cashion, "A Transit Satellite Timing Receiver," Proceedings of the Ninth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meetings. NASA Technical Memorandum 70104, 1978.

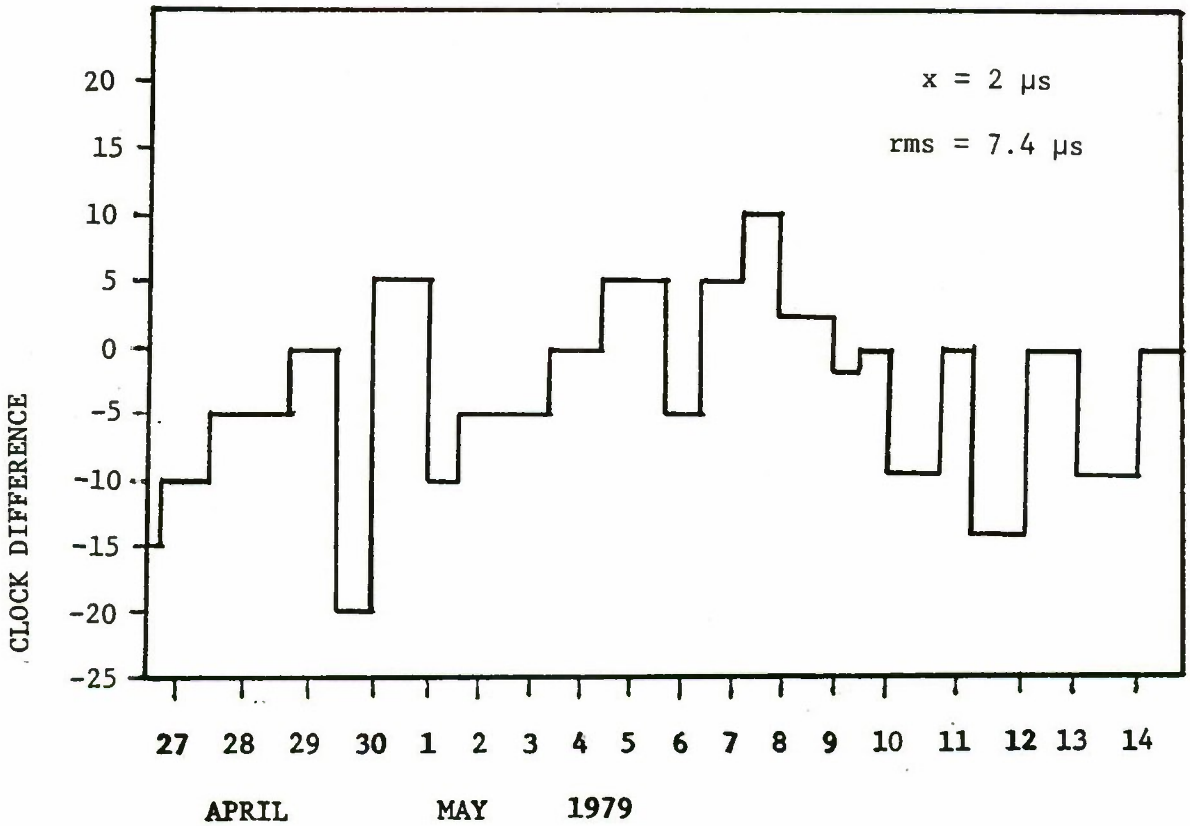


Figure 13-2 Performance Relative to USNO MC

CHAPTER 14

GLOBAL POSITIONING SYSTEM TIME TRANSFER

The advent of the Global Positioning System (GPS), with its predicted capability for time transfers on a worldwide basis to the 10-nanosecond level, promises to be a vehicle for unprecedented improvements in worldwide timekeeping.

A brief description of the GPS system is provided as background to aid in achieving some understanding of the overall system. More detailed information is available in Reference 1 to this chapter.

The GPS, as originally planned, was to consist of a space segment of 24 satellites and a ground segment of a Master Control Site (MCS) and 5 or more Monitor Sites (MS), 1 of which was to be located at the USNO. The function of the monitor sites is to receive transmissions from each of the satellites, referred to a local clock, and to retransmit this information to the MCS over secure data communications links. The function of the MCS is to correlate this information with other information, perform the necessary calculations to determine current satellite performance parameters and upload this information to the satellite on a daily, or as-needed, basis. This upload provides current information on clock performance, adjusts the clocks as necessary and provides updated navigation data. The satellites were to be equally distributed in three planes inclined to the equatorial plane of the Earth by 63° and intersectioning the equatorial plane at 120° intervals.

Due to funding cutbacks, present plans call for a space segment of 18 satellites. The elimination of 6 satellites from the system will have little adverse affect on PTTI, since at least 1 satellite will always in be view and only 1 is necessary for time recovery. Studies are presently underway to determine the best orbital configuration for navigation.

14.1 GPS SATELLITE SIGNAL

Data are transmitted from the satellites on two carrier frequencies; the primary (L_1) is at 1575.42 MHz, and the secondary (L_2) is at 1227.60 MHz. The L_1 or primary transmission is modulated by both a precision (P) code and a course/acquisition (C/A) code simultaneously. The L_2 or secondary transmission is modulated by either a P or C/A code. The data stream is transmitted at 50 bits per second and is common to both the P and C/A codes on both the L_1 and L_2 bands. All signals are derived from the same on-board clock. A complete data message is a frame of 1500 bits repeated every 6 seconds. Each frame is divided into five 300-bit subframes, which are further subdivided into ten 30-bit words. The first two words of each subframe contain telemetry and code handover information. The last eight words of Subframe 1 contain clock corrections, an age of data word and ionospheric delay model coefficients. The last eight words of Subframes 2 and 3 contain the space vehicle's ephemeris and associated age of data words. The last eight words of Subframe 4 contain an alphanumeric message of interest to users. The last eight words of Subframe 5 contain an Almanac (an abbreviated version of information in Subframes 2 and 3) for each of the satellites in the constellation. Each Subframe 5 contains information on a single satellite. Thus, the complete Almanac for the entire satellite constellation requires reception of a sequence of frames. The length of the sequence is dependent on the number of satellites in orbit, with 24 being the maximum.

In order to recover time relative to GPS, a user must be able to receive the satellite signal reliably and demodulate and decode the data stream. Utilizing this information, he can calculate a corrected pseudorange, compare it to a pseudorange measured against his clock, and from the difference, determine his clock difference. The GPS/Time Transfer Unit (TTU) described in the following paragraphs was designed to perform that function for application at a fixed, known location.

Further information on the GPS satellite signal can be found in Reference 2 to this chapter.

14.2 GPS/TTU

The GPS/TTU Block Diagram is shown in figure 14-1. A block diagram of the receiver is shown in figure 14-2. The receiver is a single channel, spread spectrum Doppler tracking receiver capable of tracking and decoding the C/A code on the L_1 frequency. It receives the signal (from antenna with nearly

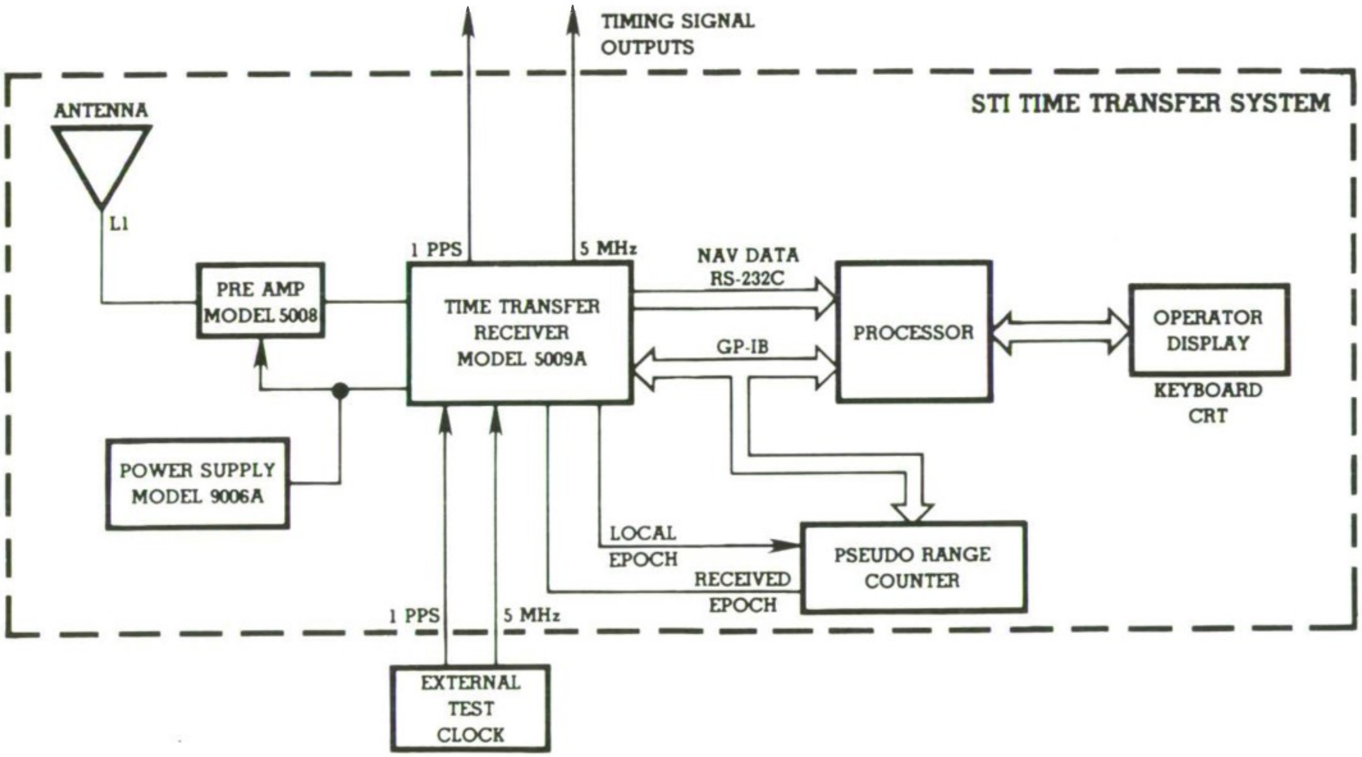


Figure 14-1 Time Transfer System

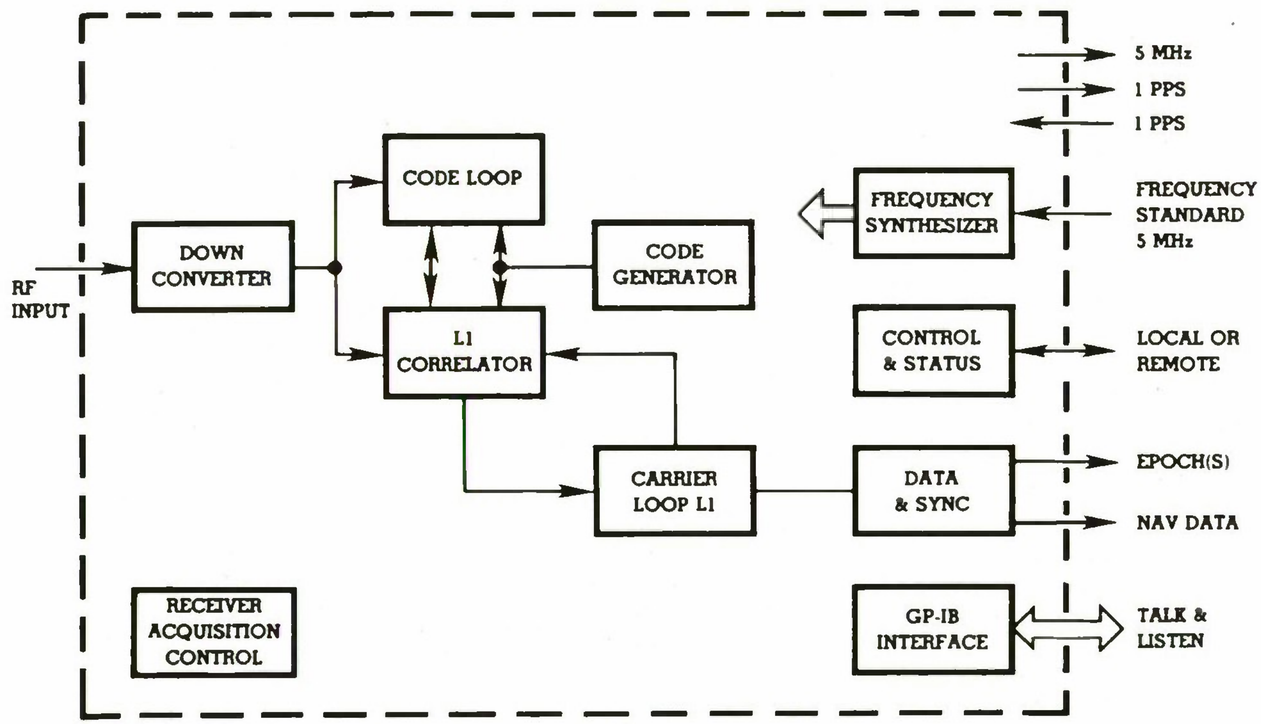


Figure 14-2 Time Transfer Receiver

hemispherical coverage) through a low noise preamplifier. Preselective filtering in the preamplifier and further filtering at the receiver limit the effect of out-of-band noise. The signal is then down-converted to an IF frequency and fed to a code loop and correlator which track the C/A code and despread the spread spectrum signal. A carrier tracking loop then demodulates the signal and provides both C/A code epochs and navigation data to detection and synchronization circuits which provide the satellite outputs to both the measurement and computer systems.

14.3 SUMMARY

It has been demonstrated that time transfers utilizing GPS and a GPS/TTU can be made to a precision of approximately 50 nanoseconds with little difficulty. By employing techniques similar to those used in TV Line-10 transfers (where simultaneous, common view measurements are made against a stable transmitter) measurements to a 10-nanosecond level should be possible. However, before day-to-day stability against an external reference such as UTC can be achieved, a more comprehensive approach to the control and synchronization of the ground clocks must be developed.

The USNO is pursuing improvement of GPS timing and attempting to make it available to users as soon as possible. The data collected by the GPS/TTU are made available via our recently inaugurated PTTI digital data service. In the future, this data will also be published in our Time Service publications. Modifications to the TTU software to allow programmed, automatic tracking of every satellite every day, and automatic transfer of the data to our on-line data acquisition systems computer have considerably enhanced the timeliness and quantity of data available. Finally, a program to improve the linkage of the GPS MCS clock ensemble to the USNO Master Clock is being pursued with the aim of eliminating the presently observed discontinuities and reducing the ground clock offsets.

REFERENCES

1. Global Positioning System, Institute of Navigation, Washington, DC, 1980.
2. System Specification for the NAVSTAR Global Positioning System, USAF Space, and Missile Systems Organization, 31 January 1979.

CHAPTER 15
DATA RECORDING AND REPORTING

15.1 TELETYPE MESSAGES

The U.S. Naval Observatory Time Service Division uses automatic data processing for all PTTI data. All field PTTI data received by teletype (TWX) is recorded on perforated paper tape that can be input directly into a data acquisition system. This direct input requires a certain rigidity in message format. The Satellite PTTI Transfer Record form was specifically developed for use by SATCOM terminals. The lower portion (Message Format), however, can be used by any PTTI activity to send messages to NAVOBSY. Detailed instructions for completing the upper section are printed on the form. The teletype message must be prepared for transmission on the bottom section, Message Format, according to the following instructions. Messages that do not conform to this format will require special handling with resulting processing delays.

Figure 15-1 is a blank sample of the Satellite PTTI Transfer Record that may be used for local reproduction. Blank forms may also be obtained by letter request to:

Superintendent
U.S. Naval Observatory
ATTN: Time Service Division
Washington, D.C. 20390

Satellite PTTI Transfer Record forms are filed in chronological order on completion of the teletype message. Records over three months old are authorized to be destroyed without report.

15.1.1 Teletype Message Format Instructions

Figure 15-2 is a sample of an entire, completed Satellite PTTI Transfer Record form. Figure 15-3 contains several samples of the Message Format section.

SATELLITE PTTI TRANSFER RECORD

DATE ____________

DISTANT SITE ____________ DISTANT CLOCK SER. NO. ____________

PTTI Form TS–2 LOCAL SITE ____________ LOCAL CLOCK SER. NO. ____________

DATE*TIME(ZULU) OF TRANSFER	DISTANT SITE READING	LOCAL SITE READING	CLOCK DIFFERENCE	REMARKS
	TICK START COMPLETED			
	TRANSFERS COMPLETED	AVERAGE		

1. CLOCK DIFFERENCE is the algebraic difference of DISTANT SITE READING minus LOCAL SITE READING, and is equal to the LOCAL CLOCK minus the DISTANT CLOCK.

   EXAMPLE: 149166.3 - 149169.8 = - 3.5 μsec

   744728.9 - 744724.2 = 4.7 μsec
2. Be sure the SIGN of the CLOCK DIFFERENCE is correct.
   DO NOT use the plus (+) sign or the word "plus" with positive values.
   The minus (–) sign MUST be used with negative values. DO NOT use the word "neg."
3. AVERAGE is the value most often recorded as the CLOCK DIFFERENCE.
4. TRANSFER COMPLETED is the time used in message report to NAVOBSY.
5. Always use LOCAL CS number, followed by DISTANT terminal designation and CS number, in the MESSAGE FORMAT below. For each time transfer, verify the local and distant CS numbers used. (See Chapter 15, NAVOBSY TS/PTTI, 1980.)
6. Keep this report on file for 3 months.

MESSAGE FORMAT

FM ____________

TO RUCLRFA/NAVOBSY WASHINGTON DC

INFO DCAOC WASHINGTON DC

BT

UNCLAS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

Y Y Y Y _

_ _ _ _ _ _ _ _

C S _ _ _ _

_ _ _ _ _ _ _ _ _ _ _ _ . _ _ _ _ _ _ _ _ . _ _ _ _ _ _ Z

_ _ _ _ _ _ _ _ _ _ _ _ . _ _ _ _ _ _ _ _ . _ _ _ _ _ _ Z

_ _ _ _ _ _ _ _ _ _ _ _ . _ _ _ _ _ _ _ _ . _ _ _ _ _ _ Z

_ _ _ _ _ _ _ _ _ _ _ _ . _ _ _ _ _ _ _ _ . _ _ _ _ _ _ Z

_ _ _ _ _ _ _ _ _ _ _ _ . _ _ _ _ _ _ _ _ . _ _ _ _ _ _ Z

N O T E S

1 . C S _ _ _ _ T I M E D E L A Y S E T T I N G S _ _ _ _ _ _ _ _ _ _ _ _ _ .

_ . _

_ . _

B T

Figure 15-1 Satellite PTTI Transfer Record

SATELLITE PTTI TRANSFER RECORD

DATE 9 SEP 80

DISTANT SITE GND/1179 DISTANT CLOCK SER. NO. 1179

LOCAL SITE FDS LOCAL CLOCK SER. NO. 1180

PTTI Form TS-2

DATE*TIME(ZULU) OF TRANSFER	DISTANT SITE READING	LOCAL SITE READING	CLOCK DIFFERENCE	REMARKS
092021Z	TICK START COMPLETED			
092025Z	149166.3	149169.8	-3.5	
092029Z	298337.9	298341.3	-3.4	
092032Z	447485.5	447489.0	-3.5	
092036Z	596631.8	596635.2	-3.4	
092041Z	991839.1	991842.6	-3.5	
092042Z	TRANSFERS COMPLETED	AVERAGE	-3.5	

1. CLOCK DIFFERENCE is the algebraic difference of DISTANT SITE READING minus LOCAL SITE READING, and is equal to the LOCAL CLOCK minus the DISTANT CLOCK.

   EXAMPLE: 149166.3 - 149169.8 = -3.5 μsec
   744728.9 - 744724.2 = 4.7 μsec

2. Be sure the SIGN of the CLOCK DIFFERENCE is correct.
   DO NOT use the plus (+) sign or the word "plus" with positive values.
   The minus (–) sign MUST be used with negative values. DO NOT use the word "neg."
3. AVERAGE is the value most often recorded as the CLOCK DIFFERENCE.
4. TRANSFER COMPLETED is the time used in message report to NAVOBSY.
5. Always use LOCAL CS number, followed by DISTANT terminal designation and CS number, in the MESSAGE FORMAT below. For each time transfer, verify the local and distant CS numbers used. (See Chapter 15, NAVOBSY TS/PTTI, 1980.)
6. Keep this report on file for 3 months.

MESSAGE FORMAT

FM CDR USACCECTC FT. DETRICK MD

TO RUCLRFA/NAVOBSY WASHINGTON DC

INFO DCAOC WASHINGTON DC

BT

UNCLAS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

YYYY FT DETRICK SATCOM

09 SEP 80

CS1180

GND/1179 -3.5 -7.0 092042Z

. . Z

. . Z

. . Z

. . Z

NOTES

1. CS1180 TIME DELAY SETTINGS 237482 474964.

.

.

BT

Figure 15-2 Satellite PTTI Transfer Record (Sample)

```
YYYY FUCHU LOR C
22 AUG 80
CS270
  9970/A -40.9  -81.8
  9970/C -41.1  -82.8
  9970/D -41.2  -82.4
  CS313   11.2   22.4
  CS544    1.4    2.8
CS365/IWO
  CS148   15.8   31.6
  CS551   24.1   48.2
BT
```

```
YYYY RICHMOND NOTSS
10 FEB 80
CS106
  9980       -7.7  -15.4
  ND/13.6     55    110
  T/12.0      19     38
  NLK         27     54
  NAA         33     66   1500Z
  WWYB        00     00
  NBA         85    170   1500Z
  GBR         33     66   1500Z
NOTES
  1. NLK, NBA POWER FAILURE AT
       100535Z.
BT
```

```
YYYY GUAM NAVCOMSTA
17 FEB 80
CS1038
  9970Z    83639.3   167278.6   0510Z
  9970Z    83639.5   167279.0   180600Z
  9970Z    83639.6   167279.2   190445Z
  NGUAM/211    0.3        0.6   19   FEB
NOTES
  CS1038 TIME DELAY SETTING 995363 1990726
  FIN/1038 PTTI SKED 190500Z WITH WHW CANCELLED BY DCA PAC.
  CS421 TIME DELAY SETTING 476321 952642.
  FIN/1038 PTTI SKED 190800Z WITH CPX/576 CANCELLED DUE EQUIP.
BT
```

Figure 15-3 Message Format Samples (Sheet 1 of 2)

```
YYYY CAPE RACE LOR C
10 JAN 80
9930
  7930 99.1  198.2
BT
```

```
YYYY EJDE LOR C
11 JAN 80
7970
  7930   4.16   8.32
CS135
  CS375  16.11  32.22
  CS251  16.69  33.38
BT
```

```
YYYY WAHIAWA DET C
06 FEB 80
CS1118
  CS1100      -2.0      -4.0
  NWC         49.6      99.2  0100Z
  NDT         35.9      71.8  0100Z
  H/11.3       5.8      11.6
  4990X  16923.8   33847.6
  WHW/1072    18.4      36.8  051940Z
  CS1100
  4990X  16925.6   33851.2
  NWC         96.8     193.6  0100Z
  H/13.6      70.1     140.2
  NDT         87.2     174.4  0100Z
NOTES
  1. CS1118 TIME DELAY SETTING 379264 758528.
  2. CS1100 TIME DELAY SETTING 763419 1526838.
BT
```

Figure 15-3 Message Format Samples (Sheet 2 of 2)

Basic Teletype PTTI Data Format

Line 1 -- YYYY LOCATION/REPORTING ACTIVITY
Line 2 -- DAY MONTH YEAR
Line 3 -- PRIMARY LOCAL REFERENCE/CLOCK SERIAL NO.
Line 4 -- SYSTEM IDENTIFICATION READING CHECK DATE/TIME
Line 5 -- . . .
-- SECONDARY LOCAL REFERENCE/CLOCK
-- SYSTEM IDENTIFICATION READING CHECK DATE/TIME
-- . . .
-- . . .
-- NOTES
-- 1. CS___TIME DELAY SETTING ______ ______. (If required)
-- 2. (Any additional information, comments, questions, etc.)
Final -- BT

Instructions

Line 1

YYYY - this symbol distinguishes PTTI from other incoming data
LOCATION - brief indication of geographic location (city, country, etc)
ACTIVITY - brief designation of activity to which the system belongs

Line 2

DAY - 2 digits indicating the day of the month (UT)
MONTH - first 3 letters of the month
YEAR - last 2 digits of the year

a. The remainder of the line must be blank.

b. DAY, MONTH, and YEAR must be separated from each other by a space. These are three separate data fields. They are used as a default day, month, and/or year for all measurements that list no DATE/TIME in line 4.

Line 3

LOCAL REFERENCE - designation of the primary local system to which the systems that follow are compared. This is the "start" pulse.

CLOCK - designation of the local atomic standard; <u>no spacing permitted</u>

a. The clock designation consists of the symbols CS(cesium), RB(rubidium), or H(hydrogen), as appropriate, followed by the last 4 digits of the unit serial number. Do not space within this designation.

<u>Line 4</u>

SYSTEM IDENTIFICATION - designation of the system being measured compared to the preceding reference system. This is the "stop" pulse.

a. <u>No space is permitted</u>. If elements must be separated, use the slash (/) sign instead of a space. Examples: CS471/P, 9970/A, H/13.1

b. Values may be derived from either 1 pps or frequency phase comparison. No distinction is necessary unless <u>both</u> are reported for the same system. In that case, the basic designation is used for 1 pps, and the designation followed by a slash (/) and the letter P is used for phase. Example: CS574, CS574/P

c. The order of the systems monitored is not fixed.

d. Indent at least two spaces.

READING - the time difference in μsec; the <u>decimal point must be included</u>

The values may be rounded to 0.1, 0.01, or 0.001 μsec, depending on the precision of the measurement.

a. <u>At least 2 spaces</u> are required preceding the READING.

b. The number of digits is not fixed.

c. The value is <u>always</u> the difference between the CS or system in line 3 <u>minus</u> the CS or system designated in line 4 format and represents the algebraic difference of distant reading minus local site reading.

d. Negative values must be immediately preceded by a minus (-) sign.

CHECK - the value of the READING multiplied by 2; the <u>decimal point must be included</u>

a. <u>At least 2 spaces</u> are required preceding the CHECK.

b. The number of digits is not fixed.

c. The sign indication is the same as the READING; the minus (-) sign must be included.

DATE/TIME - if required, may consist of one of the following combinations:

a. <u>At least 2 spaces</u> are required preceding the TIME.

b. Four digits and the letter Z, indicating the hours and minutes of the day, month, and year shown in line 2 format.

c. Six digits and the letter Z, indicating day, hours, and minutes; followed by a space; then by the three-letter month; then a space; and then a two-digit year if different from the day, month and year shown in line 2 format.

NOTE

All times are in UTC, indicated by the time zone designator Z (ZULU). UTC and Z are the equivalent of GMT or GCT. The day is in the UTC system and is not necessarily the same as the civil date.

Line 5 and subsequent lines

These lines may continue the line 4 format, or they may give a new line 3 format followed by one or more line 4 formats.

Line NOTES

If required, the line immediately following the last SYSTEM IDENTIFICATION line.

Remaining lines

These contain general information, such as power failure, missed time transfers, etc., and may be numbered consectively if desired.

a. The pertinent SYSTEM IDENTIFICATION(S) must precede the information in each note.

b. TIME DELAY settings from all stations whose cesium standard is controlled by NAVOBSY must be contained in NOTE 1.

c. The CHECK group is the TIME DELAY setting multiplied by 2.

Final line

This consists of the symbol BT, not indented. The remainder of the line must be blank.

NOTE

Do not use words in the body of the message, such as NEG, PLUS, N/A. All comments and explanations must follow the word NOTES.

CHAPTER 16

GENERAL INFORMATION

16.1 CABLE DELAY MEASUREMENTS

The physical location of some PTTI equipment (i.e., PTRS, SATCOM, LORAN-C, etc) may require a relatively large distance between the equipment and the reference clock 1 pps output due to limited cabinet space, operator accessibility, multiple system use of 1 pps, circuitous conduits, etc. If the cable distance exceeds 30 feet, the cable delay time (Δt_c) must be precisely measured and the correction applied to all timing data collected before transmission or processing. Cable delay can be measured accurately by one of the following methods.

16.1.1 Two Nearly Parallel, Equal Length Cables

a. Connect the two cables together at the distance end.

b. Connect the clock 1 pps output and the local end of one of the cables to a T-connector on an electronic counter START input.

c. Connect the local end of the other cable to the counter STOP input.

d. Record the counter reading.

e. Divide the counter reading by 2 to obtain the one-way cable delay.

16.1.2 Single Cable (Figure 16-1)

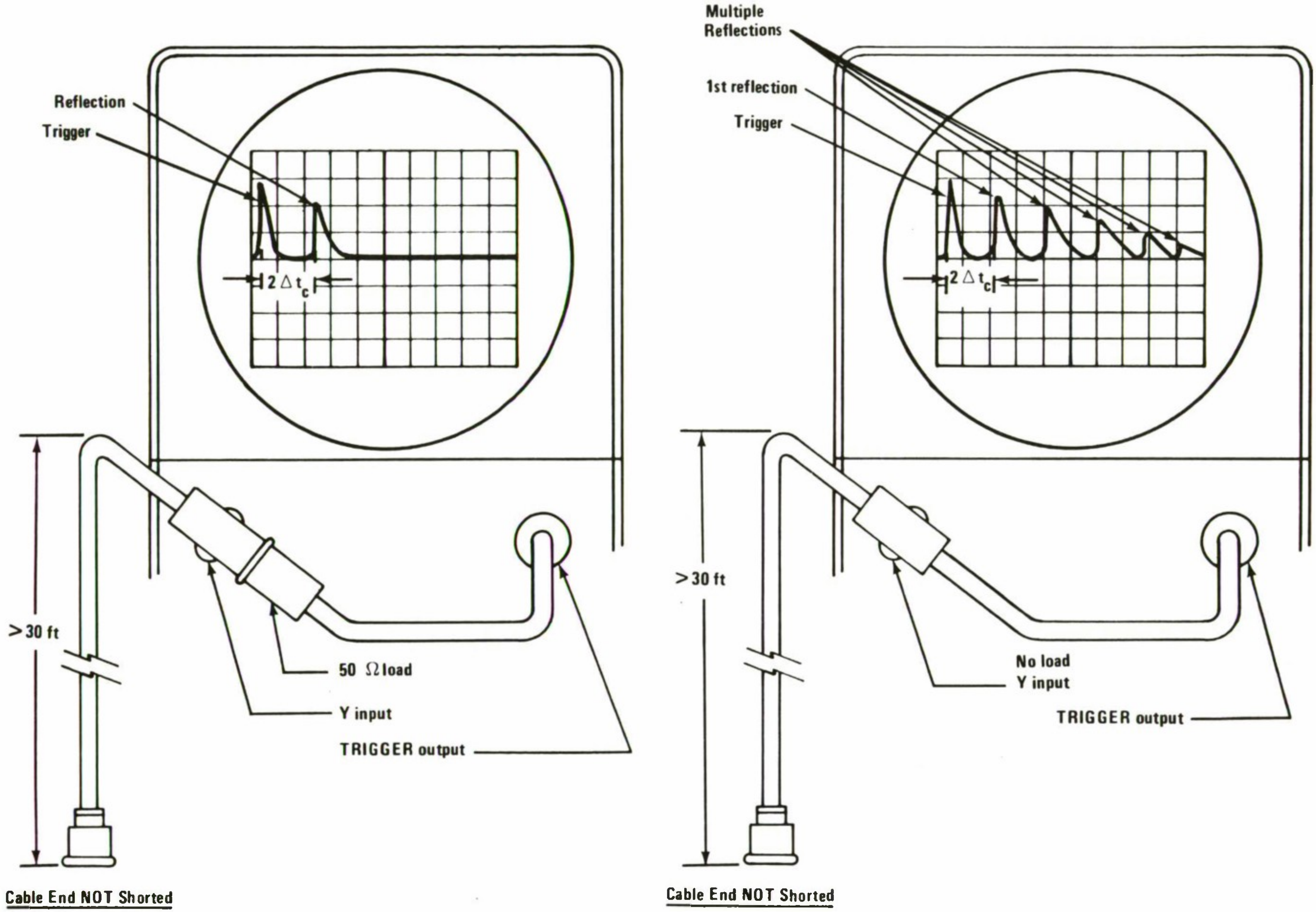
a. Obtain one of the following devices capable of generating 100 pps or 1000 pps with less than 50 nanoseconds rise time.

1. Oscilloscope with trigger output
2. Pulse generator
3. Time standard

b. Check that the distant end of the cable is not shorted.

c. Connect the 100 pps or 1000 pps source and the local end of the cable to a T-connector on an oscilloscope VERTICAL input.

d. Set the oscilloscope sweep to the FREE RUN position (100 μsec/cm or faster).



NOTE: Set sweep control to **FREE RUNNING** faster than 100 μ sec/cm

Figure 16-1 Single Cable Delay Measurement with Oscilloscope

e. The trigger pulse should appear at the beginning of the sweep, followed by the reflected pulse from the open cable end. Record the time difference between the leading edges of the two pulses.

f. Divide the time difference by 2 to obtain the one-way cable delay.

NOTE

The cable should be connected to the oscilloscope through a load that matches the impedance of the cable to provide a single reflected pulse. A cable connected with a mismatched impedance will produce multiple reflections on the oscilloscope display.

16.2 LEAP SECOND REQUIREMENTS FOR UTC TIME SCALE

Mankind has long sought the ideal reference standard that would provide a uniform time scale. At the General Assembly of the International Astronomical Union (Moscow, 1958), Ephemeris Time (ET) was defined as follows: "Ephemeris Time is reckoned from the instant, near the beginning of the calendar year A.D. 1900, when the geometric mean longitude of the Sun was $27°41'48''.04$, at which instant the measure of Ephemeris Time was 1900 January 0^d 12^h precisely." In 1967, the XIIIth General Conference of Weights and Measures defined the "atomic" second based on the hyperfine transition frequency in the Cesium 133 (natural state) atom. The Atomic Time (AT) scale, based on the atomic second, very nearly coincides with the ET scale. The duration of the second in each scale is considered to be the same, but the epochs differ in the sense that $ET = AT + 32.18^s$. (Note that the designation "Ephemeris Time" will be replaced by "Dynamical Time" in 1984.)

Astronomical observations and terrestrial navigation require a time scale based on the rotation of the Earth on its axis. This time scale is called Universal Time (UT) and is the mean solar time on the Greenwich meridian. It is based on the average motion of the Sun. Variations in the Earth's speed of rotation render UT unsuitable for timekeeping more precise than 1 millisecond. UT1 is derived by correcting UT for the observational effects of polar motion. UT2 is derived by correcting UT1 for seasonal variations in the Earth's rotation.

The U.S. Naval Observatory Atomic Time (A.1) and UT2 were considered to be in coincidence at 0000 hours 1 January 1958. UT2 was slower than A.1 and their time scales began to diverge from the moment of coincidence.

Coordinated Universal Time (UTC) combines the uniformity of AT with the functionality of UT. Figure 16-2 is a graph of the UTC and A.1 time scales. The best features of both time scales can be combined by the following method.

16.2.1 Before 0000 Hours 1 January 1972

The nominal frequency of an atomic standard (rubidium, cesium, hydrogen) was offset by a fixed amount that provided a highly uniform clock rate. Infrequent offset changes and, from 1962, 0.1 second time steps were used to maintain UTC very close to UT2. The offset was -300×10^{-10} from 0000 hours 1 January 1966 to 2400 hours 31 December 1971. The last 0.1 second time step occurred at 2400 hours 31 January 1968.

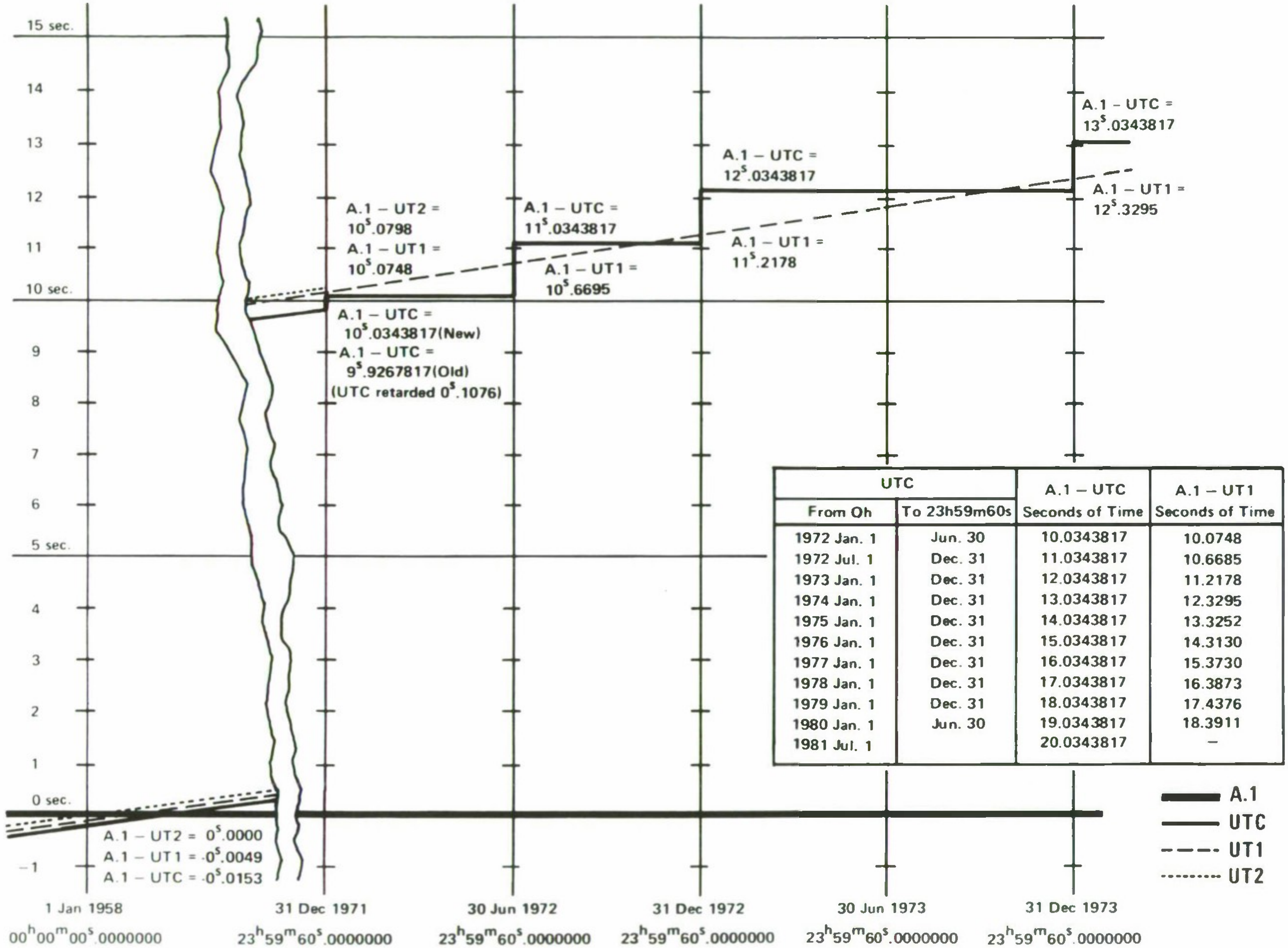
16.2.2 After 0000 Hours 1 January 1972

a. At $23^h59^m60^s.0000000$ 31 December 1971, the UTC was retarded 0.1076 second to make A.1 - UTC = $10^s.0343817$. The -300×10^{-10} frequency offset of UTC was reduced to 0, which is the frequency of the A.1 time scale. UT1 then replaced UT2 as the reference time scale for UTC.

b. UTC is adjusted periodically by exactly 1.0 second to maintain UTC within ±0.8 second of UT1. These time steps are called leap seconds.

c. Leap seconds are applied at irregular intervals, preferably at 2400 hours on 31 December. The leap second may also be applied at 2400 hours on 30 June, 31 March, or 30 September.

d. The International Bureau de L'Heure in Paris determines the need for a leap second and publishes it well in advance.



UTC		A.1 – UTC	A.1 – UT1
From Oh	To 23h59m60s	Seconds of Time	Seconds of Time
1972 Jan. 1	Jun. 30	10.0343817	10.0748
1972 Jul. 1	Dec. 31	11.0343817	10.6685
1973 Jan. 1	Dec. 31	12.0343817	11.2178
1974 Jan. 1	Dec. 31	13.0343817	12.3295
1975 Jan. 1	Dec. 31	14.0343817	13.3252
1976 Jan. 1	Dec. 31	15.0343817	14.3130
1977 Jan. 1	Dec. 31	16.0343817	15.3730
1978 Jan. 1	Dec. 31	17.0343817	16.3873
1979 Jan. 1	Dec. 31	18.0343817	17.4376
1980 Jan. 1	Jun. 30	19.0343817	18.3911
1981 Jul. 1		20.0343817	–

Figure 16-2 UTC Time Scale Graph

16.3 MODIFIED JULIAN DAY

The International Astronomical Union (IAU) and the Consultative Committee for International Radio (CCIR) have adopted the Modified Julian Day (MJD) as a convenient decimal day count for use in timekeeping. The following items were considered in adopting the MJD.

a. For various timekeeping purposes, a requirement exists for dating in a continuous sequence.

b. A proliferation of different dating systems must be avoided.

c. The Julian Day, a continuing day count, has been in use for a long time.

d. The existing Julian Day count, which refers to a Greenwich Mean Noon as the beginning of the day, must be maintained without discontinuity.

e. It is convenient to use 0000 hours UT as the beginning of a day, rather than 1200 hours UT. (Note that the classical Julian Day begins at noon of the atronomical day.)

f. A simple conversion from the classical Julian Day to a modern continuous day count is advantageous.

A Modified Julian Day, satisfying the above requirements, was adopted with the following guidelines:

a. For modern timekeeping and dating, a continuous day count, counting from 0000 hours UT with five digits for day numbering, will be used.

b. The MJD number is equal to the Julian date minus 2 400 000.5.

c. The MJD has an initial epoch of 0000 hours UT on 17 November 1858.

Therefore: MJD = 0 = 17 November 1858; MJD = 1 = 18 November 1858, etc.

16.3.1 Gregorian Calendar/MJD Conversion

Table 16-1 lists the MJD of the zeroth day of each month for the calendar years 1950 through 2000. To find the MJD for a given Gregorian data, add the day of the month to the MJD of the 0th day of the same month. For example:

Table 16-1 Modified Julian Day Number Bases for Each Calendar Month, 1950 - 2000 A.D.

YEAR	JAN.0	FEB.0	MAR.0	APR.0	MAY.0	JUN.0	JUL.0	AUG.0	SEP.0	OCT.0	NOV.0	DEC.0
1950	33281	33312	33340	33371	33401	33432	33462	33493	33524	33554	33585	33615
1951	33646	33677	33705	33736	33766	33797	33827	33858	33889	33919	33950	33980
1952	34011	34042	34071	34102	34132	34163	34193	34224	34255	34285	34316	34346
1953	34377	34408	34436	34467	34497	34528	34558	34589	34620	34650	34681	34711
1954	34742	34773	34801	34832	34862	34893	34923	34954	34985	35015	35046	35076
1955	35107	35138	35166	35197	35227	35258	35288	35319	35350	35380	35411	35441
1956	35472	35503	35532	35563	35593	35624	35654	35685	35716	35746	35777	35807
1957	35838	35869	35897	35928	35958	35989	36019	36050	36081	36111	36142	36172
1958	36203	36234	36262	36293	36323	36354	36384	36415	36446	36476	36507	36537
1959	36568	36599	36627	36658	36688	36719	36749	36780	36811	36841	36872	36902
1960	36933	36964	36993	37024	37054	37085	37115	37146	37177	37207	37238	37268
1961	37299	37330	37358	37389	37419	37450	37480	37511	37542	37572	37603	37633
1962	37664	37695	37723	37754	37784	37815	37845	37876	37907	37937	37968	37998
1963	38029	38060	38088	38119	38149	38180	38210	38241	38272	38302	38333	38363
1964	38394	38425	38454	38485	38515	38546	38576	38607	38638	38668	38699	38729
1965	38760	38791	38819	38850	38880	38911	38941	38972	39003	39033	39064	39094
1966	39125	39156	39184	39215	39245	39276	39306	39337	39368	39398	39429	39459
1967	39490	39521	39549	39580	39610	39641	39671	39702	39733	39763	39794	39824
1968	39855	39886	39915	39946	39976	40007	40037	40068	40099	40129	40160	40190
1969	40221	40252	40280	40311	40341	40372	40402	40433	40464	40494	40525	40555
1970	40586	40617	40645	40676	40706	40737	40767	40798	40829	40859	40890	40920
1971	40951	40982	41010	41041	41071	41102	41132	41163	41194	41224	41255	41285
1972	41316	41347	41376	41407	41437	41468	41498	41529	41560	41590	41621	41651
1973	41682	41713	41741	41772	41802	41833	41863	41894	41925	41955	41986	42016
1974	42047	42078	42106	42137	42167	42198	42228	42259	42290	42320	42351	42381
1975	42412	42443	42471	42502	42532	42563	42593	42624	42655	42685	42716	42746
1976	42777	42808	42837	42868	42898	42929	42959	42990	43021	43051	43082	43112
1977	43143	43174	43202	43233	43263	43294	43324	43355	43386	43416	43447	43477
1978	43508	43539	43567	43598	43628	43659	43689	43720	43751	43781	43812	43842
1979	43873	43904	43932	43963	43993	44024	44054	44085	44116	44146	44177	44207
1980	44238	44269	44298	44329	44359	44390	44420	44451	44482	44512	44543	44573
1981	44604	44635	44663	44694	44724	44755	44785	44816	44847	44877	44908	44938
1982	44969	45000	45028	45059	45089	45120	45150	45181	45212	45242	45273	45303
1983	45334	45365	45393	45424	45454	45485	45515	45546	45577	45607	45638	45668
1984	45699	45730	45759	45790	45820	45851	45881	45912	45943	45973	46004	46034
1985	46065	46096	46124	46155	46185	46216	46246	46277	46308	46338	46369	46399
1986	46430	46461	46489	46520	46550	46581	46611	46642	46673	46703	46734	46764
1987	46795	46826	46854	46885	46915	46946	46976	47007	47038	47068	47099	47129
1988	47160	47191	47220	47251	47281	47312	47342	47373	47404	47434	47465	47495
1989	47526	47557	47585	47616	47646	47677	47707	47738	47769	47799	47830	47860
1990	47891	47922	47950	47981	48011	48042	48072	48103	48134	48164	48195	48225
1991	48256	48287	48315	48346	48376	48407	48437	48468	48499	48529	48560	48590
1992	48621	48652	48681	48712	48742	48773	48803	48834	48865	48895	48926	48956
1993	48987	49018	49046	49077	49107	49138	49168	49199	49230	49260	49291	49321
1994	49352	49383	49411	49442	49472	49503	49533	49564	49595	49625	49656	49686
1995	49717	49748	49776	49807	49837	49868	49898	49929	49960	49990	50021	50051
1996	50082	50113	50142	50173	50203	50234	50264	50295	50326	50356	50387	50417
1997	50448	50479	50507	50538	50568	50599	50629	50660	50691	50721	50752	50782
1998	50813	50844	50872	50903	50933	50964	50994	51025	51056	51086	51117	51147
1999	51178	51209	51237	51268	51298	51329	51359	51390	51421	51451	51482	51512
2000	51543	51574	51603	51634	51664	51695	51725	51756	51787	51817	51848	51878

21 March 1974 = MJD 42127

42106 - MJD of 0 March 1974

+ 21 - 21st day of month

42127 - MJD of 21 March 1974

To find the Gregorian date for a given MJD, find the highest MJD 0th day value that is less than the given MJD and note the month. Subtract this value from the given MJD to obtain the day of the month. For example:

MJD 42152 = 15 April 1974

42152 - given MJD

-42137 - MJD of 0 April 1974

15 - Gregorian day of April 1974

16.3.2 Conversion to Decimal Equivalent of a Day

To convert hours, minutes, and seconds of a day to 6-digit decimals for use with MJD, use the values listed in table 16-2. Follow the procedure in the example below.

Example. To convert $21^h39^m51^s$ to the decimal equivalent of a day:

Since 21^h is more than 1/2 day, record the decimal value of 12^h.	0.500 000
Find the 9^h column value across from 39^m.	0.402 083
Find the ^{s} column value for 51.	+ 0.000 590
Add the values to obtain the decimal of the day.	0.902 673

NOTE

The leap second described in 16.2 is disregarded in converting to a decimal day for nearly all applications. In case of very long periods of continuous data, it may be included by adding or subtracting 0.000 011 574 for each leap second in the interval of time considered.

Table 16-2 Conversion of Hours, Minutes, and Seconds to Decimal of a Day

m	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	s	SECONDS
	d	d	d	d	d	d	d	d	d	d	d	d		d
0	0.000 000	0.041 667	0.083 333	0.125 000	0.166 667	0.208 333	0.250 000	0.291 667	0.333 333	0.375 000	0.416 667	0.458 333	0	0.000 000
1	.000 694	.042 361	.084 028	.125 694	.167 361	.209 028	.250 694	.292 361	.334 028	.375 694	.417 361	.459 028	1	.000 012
2	.001 389	.043 056	.084 722	.126 389	.168 056	.209 722	.251 389	.293 056	.334 722	.376 389	.418 056	.459 722	2	.000 023
3	.002 083	.043 750	.085 417	.127 083	.168 750	.210 417	.252 083	.293 750	.335 417	.377 083	.418 750	.460 417	3	.000 035
4	.002 778	.044 444	.086 111	.127 778	.169 444	.211 111	.252 778	.294 444	.336 111	.377 778	.419 444	.461 111	4	.000 046
5	0.003 472	0.045 139	0.086 806	0.128 472	0.170 139	0.211 806	0.253 472	0.295 139	0.336 806	0.378 472	0.420 139	0.461 806	5	0.000 058
6	.004 167	.045 833	.087 500	.129 167	.170 833	.212 500	.254 167	.295 833	.337 500	.379 167	.420 833	.462 500	6	.000 069
7	.004 861	.046 528	.088 194	.129 861	.171 528	.213 194	.254 861	.296 528	.338 194	.379 861	.421 528	.463 194	7	.000 081
8	.005 556	.047 222	.088 889	.130 556	.172 222	.213 889	.255 556	.297 222	.338 889	.380 556	.422 222	.463 889	8	.000 093
9	.006 250	.047 917	.089 583	.131 250	.172 917	.214 583	.256 250	.297 917	.339 583	.381 250	.422 917	.464 583	9	.000 104
10	0.006 944	0.048 611	0.090 278	0.131 944	0.173 611	0.215 278	0.256 944	0.298 611	0.340 278	0.381 944	0.423 611	0.465 278	10	0.000 116
11	.007 639	.049 306	.090 972	.132 639	.174 306	.215 972	.257 639	.299 306	.340 972	.382 639	.424 306	.465 972	11	.000 127
12	.008 333	.050 000	.091 667	.133 333	.175 000	.216 667	.258 333	.300 000	.341 667	.383 333	.425 000	.466 667	12	.000 139
13	.009 028	.050 694	.092 361	.134 028	.175 694	.217 361	.259 028	.300 694	.342 361	.384 028	.425 694	.467 361	13	.000 150
14	.009 722	.051 389	.093 056	.134 722	.176 389	.218 056	.259 722	.301 389	.343 056	.384 722	.426 389	.468 056	14	.000 162
15	0.010 417	0.052 083	0.093 750	0.135 417	0.177 083	0.218 750	0.260 417	0.302 083	0.343 750	0.385 417	0.427 083	0.468 750	15	0.000 174
16	.011 111	.052 778	.094 444	.136 111	.177 778	.219 444	.261 111	.302 778	.344 444	.386 111	.427 778	.469 444	16	.000 185
17	.011 806	.053 472	.095 139	.136 806	.178 472	.220 139	.261 806	.303 472	.345 139	.386 806	.428 472	.470 139	17	.000 197
18	.012 500	.054 167	.095 833	.137 500	.179 167	.220 833	.262 500	.304 167	.345 833	.387 500	.429 167	.470 833	18	.000 208
19	.013 194	.054 861	.096 528	.138 194	.179 861	.221 528	.263 194	.304 861	.346 528	.388 194	.429 861	.471 528	19	.000 220
20	0.013 889	0.055 556	0.097 222	0.138 889	0.180 556	0.222 222	0.263 889	0.305 556	0.347 222	0.388 889	0.430 556	0.472 222	20	0.000 231
21	.014 583	.056 250	.097 917	.139 583	.181 250	.222 917	.264 583	.306 250	.347 917	.389 583	.431 250	.472 917	21	.000 243
22	.015 278	.056 944	.098 611	.140 278	.181 944	.223 611	.265 278	.306 944	.348 611	.390 278	.431 944	.473 611	22	.000 255
23	.015 972	.057 639	.099 306	.140 972	.182 639	.224 306	.265 972	.307 639	.349 306	.390 972	.432 639	.474 306	23	.000 266
24	.016 667	.058 333	.100 000	.141 667	.183 333	.225 000	.266 667	.308 333	.350 000	.391 667	.433 333	.475 000	24	.000 278
25	0.017 361	0.059 028	0.100 694	0.142 361	0.184 028	0.225 694	0.267 361	0.309 028	0.350 694	0.392 361	0.434 028	0.475 694	25	0.000 289
26	.018 056	.059 722	.101 389	.143 056	.184 722	.226 389	.268 056	.309 722	.351 389	.393 056	.434 722	.476 389	26	.000 301
27	.018 750	.060 417	.102 083	.143 750	.185 417	.227 083	.268 750	.310 417	.352 083	.393 750	.435 417	.477 083	27	.000 312
28	.019 444	.061 111	.102 778	.144 444	.186 111	.227 778	.269 444	.311 111	.352 778	.394 444	.436 111	.477 778	28	.000 324
29	.020 139	.061 806	.103 472	.145 139	.186 806	.228 472	.270 139	.311 806	.353 472	.395 139	.436 806	.478 472	29	.000 336
30	0.020 833	0.062 500	0.104 167	0.145 833	0.187 500	0.229 167	0.270 833	0.312 500	0.354 167	0.395 833	0.437 500	0.479 167	30	0.000 347
31	.021 528	.063 194	.104 861	.146 528	.188 194	.229 861	.271 528	.313 194	.354 861	.396 528	.438 194	.479 861	31	.000 359
32	.022 222	.063 889	.105 556	.147 222	.188 889	.230 556	.272 222	.313 889	.355 556	.397 222	.438 889	.480 556	32	.000 370
33	.022 917	.064 583	.106 250	.147 917	.189 583	.231 250	.272 917	.314 583	.356 250	.397 917	.439 583	.481 250	33	.000 382
34	.023 611	.065 278	.106 944	.148 611	.190 278	.231 944	.273 611	.315 278	.356 944	.398 611	.440 278	.481 944	34	.000 394
35	0.024 306	0.065 972	0.107 639	0.149 306	0.190 972	0.232 639	0.274 306	0.315 972	0.357 639	0.399 306	0.440 972	0.482 639	35	0.000 405
36	.025 000	.066 667	.108 333	.150 000	.191 667	.233 333	.275 000	.316 667	.358 333	.400 000	.441 667	.483 333	36	.000 417
37	.025 694	.067 361	.109 028	.150 694	.192 361	.234 028	.275 694	.317 361	.359 028	.400 694	.442 361	.484 028	37	.000 428
38	.026 389	.068 056	.109 722	.151 389	.193 056	.234 722	.276 389	.318 056	.359 722	.401 389	.443 056	.484 722	38	.000 440
39	.027 083	.068 750	.110 417	.152 083	.193 750	.235 417	.277 083	.318 750	.360 417	.402 083	.443 750	.485 417	39	.000 451
40	0.027 778	0.069 444	0.111 111	0.152 778	0.194 444	0.236 111	0.277 778	0.319 444	0.361 111	0.402 778	0.444 444	0.486 111	40	0.000 463
41	.028 472	.070 139	.111 806	.153 472	.195 139	.236 806	.278 472	.320 139	.361 806	.403 472	.445 139	.486 806	41	.000 475
42	.029 167	.070 833	.112 500	.154 167	.195 833	.237 500	.279 167	.320 833	.362 500	.404 167	.445 833	.487 500	42	.000 486
43	.029 861	.071 528	.113 194	.154 861	.196 528	.238 194	.279 861	.321 528	.363 194	.404 861	.446 528	.488 194	43	.000 498
44	.030 556	.072 222	.113 889	.155 556	.197 222	.238 889	.280 556	.322 222	.363 889	.405 556	.447 222	.488 889	44	.000 509
45	0.031 250	0.072 917	0.114 583	0.156 250	0.197 917	0.239 583	0.281 250	0.322 917	0.364 583	0.406 250	0.447 917	0.489 583	45	0.000 521
46	.031 944	.073 611	.115 278	.156 944	.198 611	.240 278	.281 944	.323 611	.365 278	.406 944	.448 611	.490 278	46	.000 532
47	.032 639	.074 306	.115 972	.157 639	.199 306	.240 972	.282 639	.324 306	.365 972	.407 639	.449 306	.490 972	47	.000 544
48	.033 333	.075 000	.116 667	.158 333	.200 000	.241 667	.283 333	.325 000	.366 667	.408 333	.450 000	.491 667	48	.000 556
49	.034 028	.075 694	.117 361	.159 028	.200 694	.242 361	.284 028	.325 694	.367 361	.409 028	.450 694	.492 361	49	.000 567
50	0.034 722	0.076 389	0.118 056	0.159 722	0.201 389	0.243 056	0.284 722	0.326 389	0.368 056	0.409 722	0.451 389	0.493 056	50	0.000 579
51	.035 417	.077 083	.118 750	.160 417	.202 083	.243 750	.285 417	.327 083	.368 750	.410 417	.452 083	.493 750	51	.000 590
52	.036 111	.077 778	.119 444	.161 111	.202 778	.244 444	.286 111	.327 778	.369 444	.411 111	.452 778	.494 444	52	.000 602
53	.036 806	.078 472	.120 139	.161 806	.203 472	.245 139	.286 806	.328 472	.370 139	.411 806	.453 472	.495 139	53	.000 613
54	.037 500	.079 167	.120 833	.162 500	.204 167	.245 833	.287 500	.329 167	.370 833	.412 500	.454 167	.495 833	54	.000 625
55	0.038 194	0.079 861	0.121 528	0.163 194	0.204 861	0.246 528	0.288 194	0.329 861	0.371 528	0.413 194	0.454 861	0.496 528	55	0.000 637
56	.038 889	.080 556	.122 222	.163 889	.205 556	.247 222	.288 889	.330 556	.372 222	.413 889	.455 556	.497 222	56	.000 648
57	.039 583	.081 250	.122 917	.164 583	.206 250	.247 917	.289 583	.331 250	.372 917	.414 583	.456 250	.497 917	57	.000 660
58	.040 278	.081 944	.123 611	.165 278	.206 944	.248 611	.290 278	.331 944	.373 611	.415 278	.456 944	.498 611	58	.000 671
59	0.040 972	0.082 639	0.124 306	0.165 972	0.207 639	0.249 306	0.290 972	0.332 639	0.374 306	0.415 972	0.457 639	0.499 306	59	0.000 683